

March 15, 2015

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Washington, DC 20546-0001

Dr. Ernest Moniz, Secretary of Energy  
U.S. Department of Energy  
1000 Independence Ave., SW  
Washington, DC 20585

The Honorable John Thune, Chairman  
Committee on Commerce, Science and Transportation  
United States Senate  
Washington, DC 20510

The Honorable Lisa Murkowski, Chairwoman  
Committee on Energy & Natural Resources  
United States Senate  
Washington, DC 20510

The Honorable Lamar Smith, Chairman  
Committee on Science, Space and Technology  
United States House of Representatives  
Washington, DC 20515

Dear Dr. Córdoba, Mr. Bolden, Secretary Moniz, Chairman Thune, Chairwoman Murkowski, and Chairman Smith:

I am pleased to transmit to you the annual report of the Astronomy and Astrophysics Advisory Committee for 2014–2015.

The Astronomy and Astrophysics Advisory Committee was established under the National Science Foundation Authorization Act of 2002 Public Law 107-368 to:

- (1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy;

Dr. France Córdova  
Dr. Charles Bolden, Jr.  
Dr. Ernest Moniz  
Senator John Thune  
Senator Lisa Murkowski  
Representative Lamar Smith

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- (2) assess, and make recommendations regarding, the status of the activities of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy as they relate to the recommendations contained in the National Research Council's 2010 report entitled *New Worlds, New Horizons in Astronomy and Astrophysics*, and the recommendations contained in subsequent National Research Council reports of a similar nature;
- (3) not later than March 15 of each year, transmit a report to the Director, the Administrator of the National Aeronautics and Space Administration, the Secretary of Energy, the Committee on Commerce, Science and Transportation of the United States Senate, the Committee on Energy and Natural Resources of the United States Senate, and the Committee on Science, Space, and Technology of the United States House of Representatives, on the Advisory Committee's findings and recommendations under paragraphs (1) and (2).

The attached document is the twelfth such report. The executive summary is followed by the report, with findings and recommendations for NSF, NASA and DOE regarding their support of the nation's astronomy and astrophysics research enterprise, along with detailed recommendations concerning specific projects and programs.

I would be glad to provide you with a personal briefing if you so desire.

Sincerely yours, on behalf of the Committee,



Priscilla Cushman  
Chair, Astronomy and Astrophysics Advisory Committee

cc: Senator Bill Nelson, Ranking Member, Committee on Commerce, Science and Transportation, United States Senate  
Senator Maria Cantwell, Ranking Member, Committee on Energy & Natural Resources, United States Senate  
Representative Eddie Bernice Johnson, Ranking Member, Committee on Science, Space, and Technology, United States House of Representatives  
Senator Ted Cruz, Chairman, Subcommittee on Space, Science, and Competitiveness, Committee on Commerce, Science and Transportation, United States Senate  
Senator Gary Peters, Ranking Member, Subcommittee on Space, Science, and Competitiveness, Committee on Commerce, Science and Transportation, United States Senate  
Senator Richard Shelby, Chairman, Subcommittee on Commerce, Justice, Science, and Related Agencies, Committee on Appropriations, United States Senate  
Senator Barbara Mikulski, Ranking Member, Subcommittee on Commerce, Justice, Science, and Related Agencies, Committee on Appropriations, United States Senate  
Senator Lamar Alexander, Chairman, Subcommittee on Energy and Water Development, Committee on Appropriations, United States Senate  
Senator Dianne Feinstein, Ranking Member, Subcommittee on Energy and Water Development, Committee on Appropriations, United States Senate

Representative Barbara Comstock, Chairwoman, Subcommittee on Research and Technology,  
Committee on Science, Space and Technology, United States House of Representatives  
Representative Daniel Lipinski, Ranking Member, Subcommittee on Research and Technology,  
Committee on Science, Space and Technology, United States House of Representatives  
Representative Mike Simpson, Chairman, Subcommittee on Energy and Water Development and  
Related Agencies, Committee on Appropriations, United States House of Representatives  
Representative Marcy Kaptur, Ranking Member, Subcommittee on Energy and Water  
Development, Committee on Appropriations, United States House of Representatives  
Representative John Culberson, Chairman, Subcommittee on Commerce, Justice, Science and  
Related Agencies, Committee on Appropriations, United States House of Representatives  
Representative Chaka Fattah, Ranking Member, Subcommittee on Commerce, Justice, Science  
and Related Agencies, Committee on Appropriations, United States House of Representatives  
Representative Steven Palazzo, Chairman, Subcommittee on Space, Committee on Science, Space,  
and Technology, United States House of Representatives  
Representative Donna Edwards, Ranking Member, Subcommittee on Space, Committee on  
Science, Space, and Technology, United States House of Representatives  
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Dr. John Grunsfeld, Associate Administrator, Science Mission Directorate, National Aeronautics  
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Dr. Jo Handelsman, Associate Director for Science, Office of Science and Technology Policy,  
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Dr. Saul Gonzalez, Assistant Director, Physical Sciences, Office of Science and Technology  
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Dr. J.D. Kundu, Program Examiner, NSF, Office of Management and Budget  
Dr. Grace Hu, Program Examiner, NASA, Office of Management and Budget  
Dr. Avital Bar-Shalom, Program Examiner, DOE, Office of Management and Budget  
Dr. James Ulvestad, Director, Division of Astronomical Sciences, National Science Foundation  
Dr. Patricia Knezek, Deputy Director, Division of Astronomical Sciences, National Science  
Foundation  
Dr. Joan Schmelz, Program Director, Division of Astronomical Sciences, National Science  
Foundation

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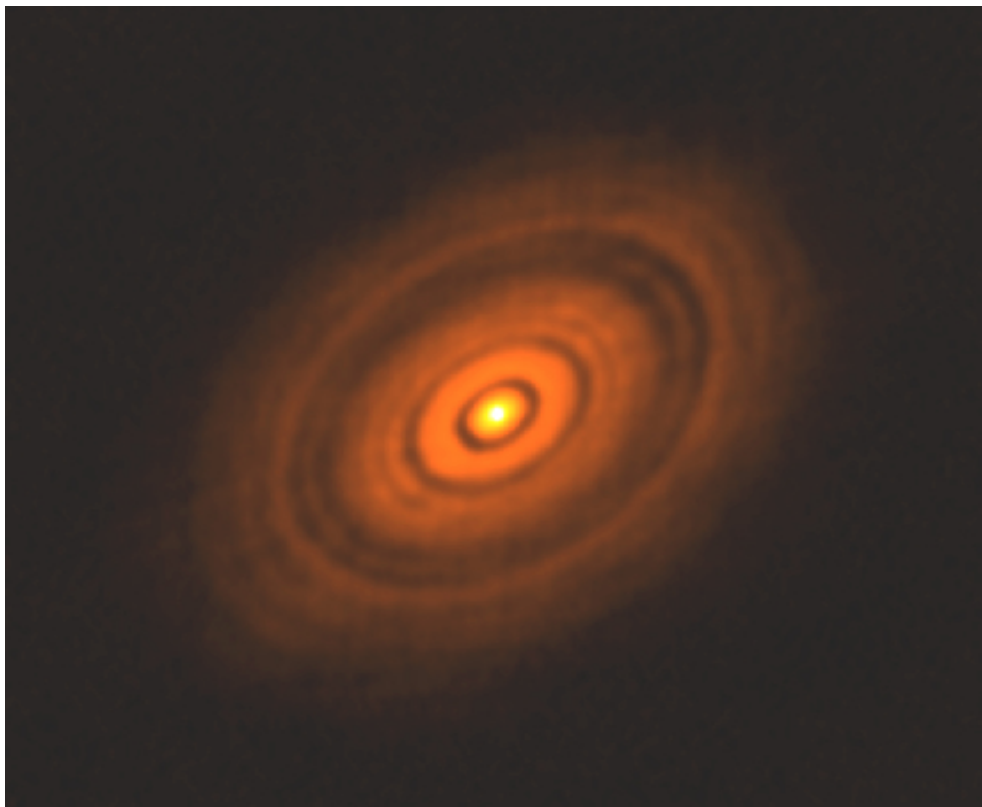
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Astronomy and Astrophysics Advisory Committee Members:

Dr. James Buckley, Washington University St. Louis  
Dr. William Cochran, University of Texas at Austin  
Dr. Priscilla Cushman, University of Minnesota, Chair  
Dr. Craig Hogan, University of Chicago  
Dr. David Hogg, New York University  
Dr. Klaus Honscheid, The Ohio State University  
Dr. Scott Hughes, MIT  
Dr. John Johnson, Harvard-SAO Center for Astrophysics  
Dr. Angela Olinto, University of Chicago, Vice-Chair  
Dr. Paula Szkody, University of Washington  
Dr. Angela Speck, University of Missouri  
Dr. Suzanne Staggs, Princeton University  
Dr. Jean Turner, UCLA

# **Report of the Astronomy and Astrophysics Advisory Committee**

March 15, 2015



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*The cover image is a planetary system in formation around the young sun-like star HL Tau taken with the newly commissioned ALMA array. See Figure A1 from the report, discussed in Appendix A.*

## **Executive Summary**

Astronomy and astrophysics directly address the most basic of human desires: to understand our place in the Universe, its origins, and whether we are alone. Over the years the U.S. has invested strongly in astronomy and astrophysics resulting in the development of amazing new windows on the Universe and answers to long-standing mysteries, while inspiring a new generation of scientists. Progress has been made possible by new telescopes and observatories with enormous power. These technological advances fuel scientific breakthroughs, and simultaneously create a climate that encourages innovation and builds the technical expertise required for our nation to compete in the future. As astronomy and astrophysics become more international enterprises, we face both opportunities for partnerships, and challenges to continued U.S. leadership.

The AAAC annual report reviews astronomy and astrophysics accomplishments over the last year, concentrating on those projects supported by the NSF Division of Astronomical Sciences, NASA Astrophysics, and the DOE Office of High Energy Physics Cosmic Frontier. The NSF Physics division and other NASA divisions have considerable overlap in many areas, and we review aspects of these programs as well. Using the priorities set down in the last Astronomy and Astrophysics decadal survey under the auspices of the National Research Council, we compare current progress and planning processes to the original roadmap. We also comment on the degree of cooperation between the agencies on projects that are supported jointly. Specifically, we emphasize the 2010 decadal survey, *New Worlds, New Horizons in Astronomy and Astrophysics (NWNH)* and its predecessors, as well as the more recent High Energy Physics Advisory Panel (HEPAP) “Particle Physics Project Prioritization Panel” (P5) subpanel’s recommendations for High Energy and Particles Physics at DOE and NSF in those disciplines that overlap with astronomy and astrophysics.

Our report tells a story of impressive accomplishments by agencies and scientists in the context of a challenging budget environment. Bold tactical choices were made by the agencies in order to keep the intent of the decadal survey intact. *NWNH* recommended several large strategic projects with breathtaking scope (see Section 4). Implementation of these projects, particularly in the face of tight budgets, has required increased agency cooperation, which in many cases has been successfully implemented. Despite the economic constraints, a series of remarkable science discoveries emerged this past year, some of which are tallied in Appendix A.

During this protracted time of constrained budgets, a particularly problematic effect has been the declining success rate of proposals. This leads scientists to spend an increasing fraction of their time on proposal writing and review panels, rather than on research and mentoring. The stress on the agencies in terms of cost, manpower, and review panel administration is likewise increasing. In response, we have begun a yearlong study of the underlying causes of this worrisome trend and the impact it could have on the field. A status report is included.

Our findings and recommendations, collected below, summarize the essential points of our report.

## Collected Findings and Recommendations

### Section 2

***FINDING:*** Thanks to a history of shared scientific goals and coordinated U.S. investment in Astronomy and Astrophysics, the U.S. program has achieved many advances and breakthroughs over the past year.

### Section 3

***FINDING:*** Dealing with complex constraints, U.S. agencies work well together to support the priorities of the scientific community, both in collaboration on large managed projects and in coordination of diverse research programs.

***FINDING:*** Interagency cooperation and collaboration has increased in the last decade, to the benefit of the science community.

### Section 4.5

***FINDING:*** The highest priorities of NWNH: WFIRST and LSST, are moving forward.

***FINDING:*** NSF/AST and DOE/HEP have done an excellent job in coordinating their efforts to make sure that LSST continues to make progress. Some delays in LSST and associated cost increases have resulted from the federal budget standoffs, but the agencies have provided good management to minimize the impact on the project.

***FINDING:*** NASA efforts to reformulate the WFIRST-AFTA concept is well underway. The NASA plan offers the potential for realizing an even more powerful experiment for Dark Energy and Extrasolar planet science in a cost-neutral way.

***FINDING:*** The NSF MSIP program is funded at a level well below that envisioned in NWNH, but is becoming the only mechanism available for funding the high priority activities advocated in NWNH. By combining support for strategic objectives with an unsolicited open call for proposals, the program may become so oversubscribed that it can no longer effectively serve the community.

***FINDING:*** Despite budgetary constraints that did not allow progress on recommendations for a U.S. partnership in a large optical/infrared telescope (GSMT) and a major new X-ray telescope (IXO), the NSF is working on a U.S. Participation Plan for the TMT and NASA is anticipating future U.S. participation in the ESA ATHENA project providing future resources for the U.S. ground-based and X-ray communities.

***FINDING:*** NSF/AST and DOE/HEP continue to support a strong dark energy program with DES and a new MIE start for DESI in 2014. Along with LSST and WFIRST/AFTA, this broad-based program across all three agencies is an excellent response to NWNH and P5 priorities in dark energy and cosmic acceleration.



***FINDING: DOE/HEP Cosmic Frontier and NSF/PHY Particle Astrophysics have selected three G2 direct detection dark matter detectors to move forward, however funding is not at the level recommended. Both agencies will continue to make the case for funding these at the level needed to carry them out successfully.***

***FINDING: The international CTA consortium is moving forward to build the CTA observatory without U.S. financial participation. Despite positive recommendations in NWNH and the P5 report, DOE has declined to support participation of U.S. scientists in CTA. For NSF, the only available funding mechanisms to support CTA construction are the highly-competed NSF/AST MSIP program and NSF/PHY Midscale Instrumentation Fund.***

***FINDING: Gravitational wave science remains one of the most exciting frontiers of physics and astrophysics, and its future development will benefit greatly from cooperation among the three agencies.***

***FINDING: CMB science clearly crosses the boundaries of agencies. As recommended by P5, a larger role of DOE with NSF is important to realize the great scientific potential of this enterprise.***

***RECOMMENDATION: We encourage DOE and NSF to continue working toward a plan for the next generation (stage-IV) ground-based CMB observatory***

***RECOMMENDATION: The agencies should continue to pursue international partnerships in order to further accomplish the goals of NWNH. The Principles for Access<sup>1</sup> should guide the process.***

## Section 4.6

***FINDING: The NSF Division of Astronomical Sciences has done a commendable job of finding creative solutions to achieve the divestment recommended by the Portfolio Review without shutting down facilities. These actions serve to reduce their operating budgets and thus to enable key scientific priorities in NWNH.***

***FINDING: Divestments recommended by the Portfolio Review are proceeding, but at a slower pace due to complexities of the divestment process.***

***FINDING: The loss of open access facilities from the NSF portfolio does not come without a cost to the U.S. user communities, in terms of loss of open nights and access to a variety of instruments and science. This loss is especially critical for the researchers at institutions without their own telescope access or who use ground-based facilities that provide unique science capabilities.***

***RECOMMENDATION: Vigorous activities toward divestments recommended by the Portfolio Review should continue, along with agency efforts to explore partnerships, interagency cooperation and private resources to maintain some access to these facilities or their capabilities for the U.S. Divestments are necessary to increase the available funding for both strategic and unsolicited midscale and individual investigator programs.***

## Section 4.7

***FINDING:*** *The agencies are commended for their collaboration in developing the mid-decadal survey process. This is the first mid-decadal review to include the NSF and DOE. They are successfully navigating the uniqueness of each agency, while maintaining a high level of coordination.*

## Section 5

***FINDING:*** *The 2016 President's Budget request proposes an overall 6% increase in R&D investment, while astronomy and astrophysics (NAF/AST, NASA/APD, DOE/HEP CF) would be flat (-0.1%) in nominal dollars before inflation, when large facility/mission construction is not included.*

***RECOMMENDATION:*** *We urge the agencies and Congress to recognize the important role of basic research to the future of our country, including the special contributions that astronomy and astrophysics can offer. Additional investments will lead to great advances and breakthroughs and the bold vision for U.S. astronomy and astrophysics endorsed in the NWNH report.*

## Section 6

***FINDING.*** *Over the last decade, the number of individuals submitting proposals to NSF and NASA in the fields of astronomy and astrophysics is increasing faster than the funding profile, causing a corresponding drop in selection rate. A larger fraction of very good to excellent proposals are unsuccessful now than in the past. Such a low selection rate for very good proposals is incompatible with the healthy individual investigator programs recommended by NWNH, and may represent a significant loss of science.*

***FINDING.*** *After accounting for changes in agency opportunities, NSF and NASA data show that the PIs submitting these proposals have remained a relatively stable demographic entity in terms of race, gender, number of years since PhD, and type of Institution.*

***FINDING.*** *A falling success rate impacts both researchers and agencies. Researchers spend a larger fraction of time re-submitting proposals and serving on multiple review panels. Agencies must deal with an increased workload, staffing problems, and ensuring fair review panels with sufficient reviewers.*

***RECOMMENDATION:*** *The agencies should continue to work with the astronomy and astrophysics community to clarify and quantify the underlying factors contributing to the declining success rate seen at NASA and NSF, and develop data-driven ideas for managing the problem.*

## 1) Introduction

Astronomy and astrophysics directly address the most basic of human desires: to understand our origins and our place in the Universe. We have made dramatic progress in understanding this story, starting with the Big Bang, through the formation of the first particles and atoms, the collapse of matter under the influence of gravity into the cosmic web of large-scale structure, the formation of galaxies, the emergence of stars and planets, and ultimately proceeding to the origin of human life on Earth. We have obtained a precise understanding of the age, shape, dynamics and fate of the Universe and have learned much about the origins of our own solar system and the evolution of life on our planet. The cosmos has also proved to be an excellent laboratory for advancing our understanding of fundamental physics, in ways that are not achievable with even the most powerful experimental apparatuses on the Earth. But there are still big questions: what is the nature of the dark matter that appears to drive the formation of structure in the Universe? What is the dark energy that is causing the rate of expansion of the Universe to increase? How common are habitable terrestrial planets in the Universe? Are we alone?

New telescopes have captivated the public with amazing astrophysical phenomena and gorgeous images of the cosmos and the wide array of beautiful and exotic objects within it. In the last couple of decades, with the rise of precision experimental cosmology, astronomy and astrophysics have provided a startling new vision of the evolution of the cosmos. The conditions in the early Universe involve energies accessible only by the largest particle accelerators. A new community of particle astrophysicists has formed to realize the potential of cosmology to illuminate fundamental laws of physics. The U.S. investment in astronomy and astrophysics has inspired a new generation of scientists and engineers in a variety of technical fields, whose innovations will provide the economic engine to power our country into the future. Fully half of the last ten Physics Nobel Prizes have deep scientific ties with our field, and two are the direct result of our national investment in astronomy and astrophysics.

This April is the 25<sup>th</sup> anniversary of the Hubble Space Telescope with celebrations around the world. The landmark science enabled by this great observatory went far beyond what even the most visionary scientists might have imagined, leading to the discovery of unexpected phenomena and in some cases even initiating new fields of astronomy. At the same time, our years with Hubble have underscored the important synergy of space based and ground-based observatories, the importance of multi-messenger observations (across the electromagnetic spectrum) and the importance of cooperation among NASA, NSF, and DOE in coordinating space and ground-based observations to achieve common scientific goals. In the same way, Hubble's successor, the James Webb Space Telescope (JWST), will open up worlds we cannot yet imagine, providing even deeper views into greater cosmic distances and earlier cosmic times. As we learned from Hubble, we can expect surprises as we launch another exploratory voyage into the unknown.

The 2015 Annual AAAC report highlights some of the impressive achievements made over the last year and makes recommendations intended to enhance our success in the future. In addition, we explore issues that are crucial to the success of these research goals. Last year the AAAC drafted a

recommendation for *Principles for Access*<sup>1</sup>, meant to guide the negotiation of astronomy and astrophysics partnerships with international and private partners, in order to implement the practices of “open access” and “open skies” which are crucial to maximizing U.S. investments in science. This year we address the increasing pressure on researchers and funding agencies due to the rise in the number of grant proposals and the resulting plummeting proposal acceptance rates. A working group to address proposal pressures was formed in Fall 2014, with a final report anticipated by the end of 2015. We present a progress report on their initial findings in Section 6.

In recent years our nation has endured challenging economic times, impacting every sphere of life. The U.S. astronomy and astrophysics research community has shared in this burden. In this report we recognize the impressive job that the community and the agencies have done to support the best possible science with limited resources, but we also identify how our progress has been slowed or diverted by economic circumstances. Basic research is crucial to the future competitiveness of the country, including the special contributions astronomy and astrophysics provide in groundbreaking technological advances, educational resources, and their power to inspire. We urge the agencies and Congress to consider how increased investment in astronomy and astrophysics would benefit this nation. In this spirit, we point out opportunities to more fully realize the bold scientific vision endorsed by U.S. advisory groups should a more positive funding climate become possible.

The AAAC advises the DOE, NASA, and NSF on issues within the field of astronomy and astrophysics that are of mutual interest and concern. Established by the NSF Authorization Act of 2002, the AAAC is chartered<sup>2</sup> to assess and make recommendations regarding the coordination of the agencies’ astronomy programs, to assess the status and make recommendations regarding agency activities as they relate to the National Research Council (NRC) astronomy and astrophysics decadal surveys, and to report the committee’s assessments and recommendations annually to the Secretary of Energy, the NASA Administrator, the NSF Director, and to relevant committees in the House and Senate. This communication represents the annual report of the current committee and includes an examination of interagency coordination, particularly in the context of the 2010 NRC Decadal Survey (*NWNH*) and its predecessors, as well as the newer “Particle Physics Project Prioritization Panel” (P5) recommendations to DOE High Energy Physics, which overlap in key areas.

Since March 15, 2014, the AAAC has had two face-to-face meetings and two teleconferences. Representatives of the NSF Division of Astronomical Sciences (NSF/AST), NSF Division of Physics (NSF/PHY) program in Particle Astrophysics, NASA Astrophysics Division (NASA/APD), and DOE High Energy Physics (DOE/HEP) at the Cosmic Frontier have given briefings and provided input on the status of their programs.

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<sup>1</sup> [http://www.nsf.gov/mps/ast/aaac/aaac\\_2014\\_principles\\_for\\_access.pdf](http://www.nsf.gov/mps/ast/aaac/aaac_2014_principles_for_access.pdf)

<sup>2</sup> The AAAC charter can be found here: <http://www.nsf.gov/mps/ast/aaac/charter.pdf>

## 2) Science Highlights

Here we list a sample of astrophysics milestones in the last year. We expand further on these in Appendix A. These topics represent just a small fraction of the extensive advances in astronomy and astrophysics breakthroughs in the last year.

**A1.** The Atacama Large Millimeter/submillimeter Array (ALMA) began a campaign of long baseline science verification observations in 2014 and has already taken images with spatial resolutions of 30 milli-arcseconds, a tenfold improvement over other arrays, and more than 200 times better than can be achieved by single dish submillimeter telescopes. Among the astronomical targets were a planetary system in formation around the young star HL Tau (cover image) and an ultra-luminous galaxy from the very early Universe, which reveals a perfectly-centered gravitationally-lensed image.

**A2.** In the few years since its launch, the high-energy X-ray imaging telescope NuSTAR has made numerous discoveries about exploding stars, black holes, pulsars, active galaxies and even our own sun. It recently made a new type of X-ray image of the remnant of a young supernova, Cassiopeia A, that may help to reveal details about how massive stars end their lives in energetic supernova explosions.

**A3.** The Dark Energy Survey (DES) completed the second of five observing seasons. The DES data sample now encompasses the largest volume of the Universe ever observed by an optical, near-infrared galaxy survey. Even data from the preceding science verification period has revealed over 1000 high-redshift supernovae and 20 trans-Neptunian minor planets. Eight new, ultra-faint Milky Way companions have been detected in the year 1 data sample.

**A4.** The European Space Agency *Rosetta* spacecraft, which carries three scientific instruments supplied by NASA, arrived at Comet 67P/Churyumov–Gerasimenko in August 2014. On 12 November 2014, Rosetta deployed the Philae landing probe to make the first soft-landing on a comet surface.

**A5.** The AAAS *Breaking News* reported that scientists have found the first candidate for a unique class of objects that were predicted to exist in 1975. These objects, named for theorists Kip Thorne and Anna Zytlow, are the result of a massive red supergiant star swallowing a neutron star companion, which in turn powers the supergiant.

**A6.** In a press release at the January 2015 AAS meeting, STScI revealed that astronomers using the ultraviolet capabilities on the Hubble Space Telescope were able to obtain the first measurements of the velocity and composition of the mysterious giant lobes of gas that exist 30,000 light years above and below the plane of our galaxy. The extreme velocities match the Fermi Bubbles discovered in high energy Gamma rays 5 years ago and indicate that a violent eruption from the center of our galaxy occurred more than 2 million years ago.

***FINDING: Thanks to a history of shared scientific goals and coordinated U.S. investment in Astronomy and Astrophysics, the U.S. program has achieved many advances and breakthroughs over the past year.***

### **3) Interagency Coordination and Cooperation**

The field of astronomy and astrophysics studies is broad, from the Big Bang to the large-scale structure of the Universe today, from stars to subatomic particles. The broad scope of this scientific endeavor brings with it diverse and complementary research goals, techniques, opportunities, and challenges. The U.S. government supports this rich field through various agencies with different, complementary missions and capabilities. When they work effectively together, they empower unique U.S. leadership in some of the most exciting frontiers of exploration.

The National Science Foundation funds a comprehensive program, comprising university grants, mid-scale experiments, facilities and centers, and large, open-access, world-class observatories. Its mission is to advance science and education generally, for the benefit of the country. The general astrophysics community sets strategic priorities for facilities. Research support is based on proposal peer review, mostly at the level of individual university investigators. Astrophysics is supported by several different programs within NSF: the Divisions of Astronomical Sciences, Physics (both particle astrophysics and gravity), and Polar Programs.

The Department of Energy, through the Office of High Energy Physics (HEP), also funds a significant research effort in astrophysics. The research goals, by policy, are narrower than NSF, and aimed at understanding the fundamental nature of matter, energy, space, and time. Peer-reviewed research allocations are often informed by strategic collaborations and organized around large, long-term experimental projects. Funding of individual investigator grants is tied to DOE science goals, but the instruments designed and built by researchers and national laboratories also empower astrophysical research beyond the agency's specific science goals.

NASA sends spacecraft and instruments into the upper atmosphere, into orbit, and into deep space. It supports science shaped by a mission-driven approach. Missions can be scientist-driven ("Explorers") or strategic ("Great Observatories"). Scientists and engineers at NASA's centers lead a wide range of R&D and missions, in partnership with aerospace industrial contractors. An extensive university grants program is also funded, including postdoctoral fellowship and grants associated with use of the Great Observatories.

There are many successful examples of the three agencies working cooperatively. One successful paradigm is the program of cosmic surveys: SDSS (begun in 1990), DES (currently collecting data), DESI (in development) and LSST (recently approved for construction, and to conclude its main operations around 2032). The details of these projects and their acronyms are found in Section 4.5. Often in these projects, which have transformed not only astronomy but also much of science, NSF provides the telescope, DOE contributes the instrument, and both bring computational and scientific analysis expertise. NASA also partners with both of the other agencies; for example, the Fermi Gamma-ray Space Telescope had principal instruments built by DOE, and ground-based follow-up observations enabled by NSF. NASA is building an instrument for the NSF/NOAO WIYN 3.5 m telescope to amplify the science impact of the TESS spacecraft. The Hubble Space Telescope routinely makes observations that benefit from complementary observations from the ground: for example, by larger aperture telescopes, or radio wave observations. Many projects also have significant investment from the private sector.

The missions of agencies, and their science goals, are shaped by national policy, and by advice from interlocking and overlapping science communities covering the whole range of astrophysics. At one level, there are relatively informal, grass-roots community groups (“PAGs” for NASA, “Community Summer Study” groups for DOE). Formal advice is obtained through committees guided by the Federal Advisory Committee Act (FACA). These are MPSAC for NSF (including important ad hoc subcommittees such as the Portfolio Review); HEPAP for DOE and NSF/PHY (including the subcommittee P5 that assigns strategic priorities for major projects); the NASA Advisory Committee (NAC)/Astrophysics Subcommittee for NASA astrophysics. Our committee, the AAAC, is also a FACA committee and one of its specific mandates is to offer advice about coordination among agencies.

In addition, a highly formal strategic process is commissioned by the agencies and managed by the National Research Council (NRC) that culminates in a strategic “Decadal Survey” of astronomy and astrophysics, most recently, *NWNH*. The NRC, through its Committee on Astronomy and Astrophysics, will soon begin a “mid-decadal review” to determine how well the agencies are following the recommended strategy, as well as to make any required course corrections.

These advisory bodies often have overlapping charges. The various agencies combine advice from multiple sources to assemble their programs. For NASA and NSF, the decadal survey is the main strategic playbook for long term planning; for DOE, it is balanced with the HEP-wide priorities laid out in the P5 report. Fortunately, the priorities are mostly well aligned at present where they overlap. For the time being, there seems to be a clear path forward for cooperation on several major initiatives.

In recent years, program directors at the three agencies have worked effectively together to coordinate their programs, and to collaborate on projects. They use effective tools such as Joint Oversight Groups (JOGs) to facilitate communication and coordination. They have helped the science community to take advantage of the particular strengths of each agency. Each large strategic project brings its own complexities to the coordination process, so this work will continue to rely on flexible, communicative and creative agency leaders.

***FINDING: Dealing with complex constraints, U.S. agencies work well together to support the priorities of the scientific community, both in collaboration on large managed projects and in coordination of diverse research programs.***

***FINDING: Interagency cooperation and collaboration has increased in the last decade, to the benefit of the science community.***

## **4) Status and Implementation of Decadal Surveys**

### **4.1 Overview**

A key part of the charge to the AAAC is to report on progress by the funding agencies on the programs and recommendations made by the Decadal Survey reports from the NRC. *NWNH* implementation is also impacted by other planning exercises, especially the recent P5 prioritization process in Particle Physics, which has considerable overlap through the DOE Comic Frontier.

Here we assess the status of the ongoing efforts of these agencies to implement the recommendations of *NWNH*, and assess the level of interagency cooperation required to achieve many of these scientific goals. Astrophysics is an increasingly international endeavor, with project budgets reaching a level such that duplication of effort is not possible; international cooperation can be the key element that allows the U.S. agencies to achieve all of the goals of these community roadmaps. In some cases, where the U.S. cannot take a leading role due to budget constraints, participation in international projects can provide a mechanism for furnishing continuity of scientific communities in the U.S. and for maintaining key infrastructure needed to keep the U.S. competitive in the coming decades. Together with private partnerships, these international partnerships with the U.S. agencies should adhere to the *Principles for Access*<sup>1</sup> in order to ensure that the U.S. scientific community is best served.

## **4.2 Major Programs currently under construction or commissioning**

Although the focus of our report is on the 2010 Astrophysics Decadal Survey (*NWNH*), we also comment on several large projects from prior surveys, that are either still under construction or whose ongoing operations constitute large and ongoing financial commitments that influence the implementation of *NWNH*.

**ALMA:** The Atacama Large Millimeter/submillimeter Array (ALMA) was inaugurated in March 2013, and the final antenna was delivered to the high site in October 2013. All North American construction deliverables were complete as of early this year. Current operations are a mix of early science and commissioning activities, as the capabilities of ALMA continue to be developed. Fall of 2014 saw the first extended campaign of long baseline observations, leading to the dramatic science verification image of the proto-planetary disk in HL Tau; disks are extremely difficult imaging targets for synthesis arrays and the success of this image demonstrates the high image fidelity for which ALMA was designed. Cycle 2 observing continues through summer of 2015, and the Cycle 3 call for proposals will be in March 2015.

**JWST:** The James Webb Space Telescope will be the most powerful telescope ever launched into space. Its four science instruments will operate in the near and mid-infrared, wavelengths at which light is better able to penetrate regions of gas and dust and particularly well-suited to the study of highly redshifted stars and galaxies of the early Universe. 2014 was the peak-funding year for JWST, during which many milestones were met. The 70-foot sunshield went through a successful full scale deployment test; the four science instruments passed a second cryo vacuum test of the Integrated Science Instrument Module (ISIM) at 40 Kelvin; and the tripod for the secondary mirror went through a successful deployment. In 2015 the full 18-mirror primary array will be constructed, followed by integration of all telescope components and testing of the observatory at Johnson Space Center in 2016 and 2017. JWST is on track for its planned October 2018 launch date.

**DKIST (formerly ATST):** Construction of the Daniel K. Inouye Solar Telescope (DKIST) is proceeding for a 2019 completion date. The primary mirror is undergoing grinding and polishing, the M2 Mirror is complete, the enclosure was integrated at the summit at the end of 2014 and the instruments are in various stages of design phases. The software and control groups are progressing with their design



reviews. The Science Working Group continued refining the Critical Science Plan and the Data Center science requirements.

**SOFIA:** The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a 100-inch telescope mounted on a Boeing 747 that covers mid and far-infrared wavelengths, which are otherwise only accessible from space. This spectral region covers the peak wavelengths at which interstellar dust emits and the most important spectral lines for cooling of the interstellar medium. The observatory is funded jointly by NASA and the German Aerospace Center. SOFIA completed commissioning and entered its prime operations phase in May 2014. After heavy maintenance at the Lufthansa facility in Hamburg, it returned to the U.S, and in January 2015 began the third season of science flights. Seventy flights are anticipated and more than 400 hours of science observations. In June 2015, the science flights will be based out of Christchurch, New Zealand, to observe the Galactic Center and other parts of the sky not visible from the Northern Hemisphere. NSF's Division of Polar Programs will support these operations.

**LIGO:** Advanced LIGO, a ground-based gravitational wave experiment, will complete its installation and initial commissioning in Summer 2015, and is expected to begin science operations in Fall 2015. Improved sensitivity will be achieved in stages, with the detectors expected to reach their final sensitivity in 2017-18. Advanced LIGO will be more sensitive than the initial LIGO interferometers by about a factor of ten (corresponding to a 1000-fold increase in sensitive volume), with greatly improved sensitivity at low frequencies where a great deal of information is carried by anticipated gravitational wave sources. The advanced detectors are expected to have a range of 200 megaparsecs to detect a binary neutron star in-spiral, far enough that several such events per year are expected to be measured.

### **4.3 *NWNH* Priorities and Recommendations**

The 2010 NRC decadal survey report *NWNH* identified three broad scientific objectives aimed at understanding our origins: (1) exploring how the first stars, galaxies and black holes came to be, (2) looking for new worlds, or nearby habitable planets beyond our solar system, and (3) using astronomical measurements to unravel the mysteries of gravity and fundamental physics beyond the reach of Earth-based experiments. *NWNH* identified a number of priorities for both ground and space-based experiments to address these broad goals, as well as providing guidance for the technology development programs and theoretical studies that move beyond the current decade to future experiments. The recommendations of *NWNH* serve as critical guidance for NASA/APD and NSF/AST, but also affect other agencies. In particular, these recommendations impact NSF/PHY and the High Energy Physics (HEP) division of the Department of Energy (DOE).

*NWNH* identified the following large projects, both in space and on the ground, as highest priority.

#### **4.3.1 Space-based Projects**

(1) The *Wide-Field Infrared Survey Telescope* (WFIRST) — an observatory designed to answer essential questions in exoplanet and dark energy research, advancing topics ranging from galaxy evolution to the study of objects within our own galaxy.

(2) *The Explorers Program*— provides frequent flight opportunities for innovative space investigations within the helio and astrophysics science areas, and opportunities for new scientific and technical ideas.

(3) The *Laser Interferometer Space Antenna* (LISA)—a low- frequency gravitational wave observatory that will open a new window on the cosmos by measuring ripples in space-time caused by many new sources, including nearby white dwarf stars and black holes.

(4) The *International X-ray Observatory* (IXO)—a major new X-ray telescope for studies of the high-energy Universe.

#### **4.3.2 Ground-based Projects**

(1) *Large Synoptic Survey Telescope* (LSST)—a wide-field optical survey telescope for dark energy science, as well as a broad program of astrophysics and planetary astronomy.

(2) The *Midscale Innovations Program* (MSIP) —a competed grant programs to augment support for mid-scale programs, designed to respond rapidly to scientific discovery and technical advances with new telescopes and instruments.

(3) The *Giant Segmented Mirror Telescope* (GSMT)—a 25% share in a large optical and near-infrared telescope that will provide a spectroscopic infrared and optical complement to the James Webb Space Telescope (JWST), the Atacama Large Millimeter Array (ALMA), and LSST.

(4) *Atmospheric Čerenkov Telescope Array* (ACTA or simply CTA)—participation in an international instrument for high-energy gamma-ray astrophysics.

### **4.4 P5 priorities and coordination with NWNH**

The DOE identified three broadly defined categories within High Energy Physics: the Intensity Frontier (neutrino experiments and precision measurements), the Energy Frontier (high energy particle accelerators) and the Cosmic Frontier (probing the fundamental physics of cosmological or astrophysical processes). All three frontiers are under the purview of HEPAP, but only the Cosmic Frontier overlaps with the projects prioritized in *NWNH* and assessed by the AAAC. The DOE (Cosmic Frontier) closely follows the priorities of the *NWNH* decadal survey, but looks for advice from its advisory panel (HEPAP) and the project prioritization subpanel of HEPAP called P5.

Two out of the five science drivers in the 2014 P5 report<sup>3</sup> concern the Cosmic Frontier (CF), namely

- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation

Under dark energy, P5 placed the LSST at the highest priority, with DOE taking the lead in the development of the wide field camera. The P5 report also recommended DOE/HEP CF support for the DESI project, a wide-field spectroscopic survey instrument, in all but the lowest budget scenarios. Under dark matter, they recommended proceeding to a generation-2 (G2) suite of dark matter experiments under all budget scenarios. Under more favorable budget scenarios it was recommended that the DOE invest in indirect dark matter detection projects such as the international Čerenkov Telescope Array (CTA), which was ranked the 4<sup>th</sup> ground-based priority in the *NWNH* survey.

In a new development, the P5 report emphasized the importance of a DOE role in future experiments aimed at measuring detailed properties of the cosmic microwave background (CMB) advocating that

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<sup>3</sup> <http://science.energy.gov/hep/hepap/reports>

work toward the next generation ground-based CMB project should become part of the planning portfolio.

## 4.5 Implementation of the Planning Recommendations

Budget realities have been significantly harsher than anticipated in *NWNH*, and have fallen well below even the most conservative budget scenarios considered there. For P5 planning, the budget realities are between the lowest and middle scenarios. Within this context, the AAAC finds that, in most cases, NASA, NSF and DOE are all making good efforts to address the underlying scientific priorities even though they are not able to fully fund some of the recommended projects. They have accomplished this by identifying areas where international collaboration might help to achieve the same goals (e.g., the LISA pathfinder instrument, or participation in the European Space Agency Advanced Telescope for High Energy Astrophysics (ATHENA) X-ray satellite), by mid-scale programs that might be able to support initial studies or technology development for future large projects (e.g., the development of the Astrophysics Focused Telescope Assets, AFTA, concept for WFIRST), or where a combination of mid-scale support and international participation may allow the U.S. to continue to play a role in science (e.g., ATHENA and TMT).

Specifically, the agencies have made progress in addressing the *NWNH* priorities for large projects as described in sections 4.5.1 and 4.5.2, below. Other details may also be found in the NSF/AST March 2015 Dear Colleague Letter<sup>4</sup> and the NASA/APD Implementation Plan<sup>5</sup>

### 4.5.1 Space-based Projects

**WFIRST:** The Wide-Field Infrared Survey Telescope (WFIRST) was the highest priority large space mission in the *NWNH* report. WFIRST is a NASA observatory designed to perform wide-field imaging and spectroscopic surveys of the near infrared (NIR) sky. The current Astrophysics Focused Telescope Assets (AFTA) design makes use of an existing 2.4m telescope designed for space. WFIRST-AFTA will settle essential questions in both exoplanet and dark energy research. NASA FY14 and FY15 appropriations support pre-formulation of WFIRST-AFTA; FY15 funds and the FY16 request will support technology development for the detectors and coronagraph. A NRC study report released in March 2014 offers a positive view of AFTA, with concerns about technology and cost risks<sup>6</sup>. The final WFIRST-AFTA Science Definition Team report was released in March 2015<sup>7</sup>.

**The Explorers Program:** Responding to the *NWNH* recommendation to maintain and, if possible, augment this program, the FY15 budget request supports a growing Astrophysics Explorers program, with continued development of explorer missions such as NICER (Neutron star Interior Composition Explorer to be launched in August 2016) and TESS (Transiting Exoplanet Survey Satellite with a launch

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<sup>4</sup> <http://www.nsf.gov/pubs/2015/nsf15044/nsf15044.pdf>

<sup>5</sup> [http://science.nasa.gov/media/medialibrary/2015/01/16/ImpPlan\\_Rev2\\_15Apr2013\\_LL\\_150107TAGGED.pdf](http://science.nasa.gov/media/medialibrary/2015/01/16/ImpPlan_Rev2_15Apr2013_LL_150107TAGGED.pdf)

<sup>6</sup> <http://www.nap.edu/catalog/18712/evaluation-of-the-implementation-of-wfirstafta-in-the-context-of-new-worlds-new-horizons-in-astronomy-and-astronautics>

<sup>7</sup> [http://wfirst.gsfc.nasa.gov/science/sdt\\_public/WFIRST-AFTA\\_SDT\\_Report\\_150310\\_Final.pdf](http://wfirst.gsfc.nasa.gov/science/sdt_public/WFIRST-AFTA_SDT_Report_150310_Final.pdf)

readiness date of August 2017). A recent opportunity for the next Small Explorer mission and Explorer Mission of Opportunity received ~25 proposals. A new Explorers opportunity is planned for FY17.

**LISA:** A space-based gravitational wave observatory ranked as a high priority for a strategic mission in *NWNH*. Budget constraints have slowed the pace of technology investment on the U.S. side. A technology mission, LISA Pathfinder, led by ESA with NASA partnership, will launch later this year. NASA plans to partner with ESA on its eLISA, mission, with a tentative launch date of 2034. The strength of the U.S. gravitational wave community has grown considerably in recent years, driven by their leadership in LIGO and Advanced LIGO slated to take data in Fall 2015. Interagency cooperation and creativity are vital in parlaying the leading role of the U.S. in the ground-based work into substantive participation in a space-based gravitational wave observatory.

**IXO:** A next-generation X-ray observatory also ranked as a high priority in *NWNH*. The constrained NASA budget complicated planning for an international observatory. In 2014, ESA selected a re-scoped X-ray mission, called Advanced Telescope for High Energy Astrophysics (ATHENA), with a launch planned in 2028. NASA is working with ESA to define a possible NASA contribution; in November 2014, NASA issued a letter asking for community participation in the ATHENA Science Study Team Working Groups.

#### **4.5.2 Ground-based Projects**

**LSST:** This top priority *NWNH* ground-based project has now moved into the construction phase. The DOE and NSF have a joint oversight group, and regularly meet with OSTP and OMB. The NSF has approved LSST construction under Major Research Equipment and Facilities Construction (MREFC) funding, and formal authorization was made on August 1, 2014. The monolithic primary mirror with integrated tertiary is approaching completion at the University of Arizona's Steward Observatory Mirror Lab, an activity funded with early private funds. DOE has approved funding for the LSST camera fabrication; the SLAC camera team successfully passed review of their performance baseline (CD-2 review). LSST initiated a cadence workshop series in August 2014 to promote engagement with the diverse community preparing for the LSST data. In looking ahead to LSST operations, NSF/AST has commissioned a NRC study of U.S. optical and infrared astronomy in the era of LSST. The report is expected in Spring 2015.

**NSF Mid-Scale Innovations Program (MSIP):** The AAAC is encouraged by the progress that NSF/AST has made in advancing the new MSIP program. This program also replaces the Telescope Systems Instrumentation Program (TSIP) and University Radio Observatories (URO), both now subsumed under the MSIP program. The first MSIP solicitation in FY2013 was for FY2014-2015 funds. Three full awards were made (the Zwicky Transient Facility, Advanced ACTPol, and the Event Horizon Telescope), as well as one development award for 2014 (HERA: Illuminating Our Early Universe). Two more are pending for 2015 and a new solicitation will be sent out at the end of the year, if the budget allows.

**GSMT:** Due to budget restrictions, NSF has not been able to enter into a direct partnership with a large telescope, as recommended by *NWNH*. In 2013, NSF and the Thirty Meter Telescope (TMT) project entered into a cooperative agreement to engage the U.S. community in planning and development. The TMT science working group will deliver a U.S. TMT Participation Plan for the NSF by the end of 2015. A

survey of the community was conducted in Sept-Oct 2014 with the results to be included in the report to the NSF. The University of Hawaii signed the TMT sub-lease in July 2014. First light is expected in the early 2020s.

**CTA:** Despite the high value of indirect detection of dark matter and its complementarity to direct detection, DOE has no plans to provide project support or R&D for U.S. participation in the international CTA project. This decision is closely coupled to the similar decision of NSF/AST not to move forward with CTA as a strategic initiative. Without U.S. funding, however, U.S. access to data from the instrument is uncertain, and the large U.S. high-energy gamma-ray community lacks a role in any major observatory or mission after the end of VERITAS or the eventual end of the Fermi satellite operations. Without a U.S. contribution, it is unlikely that the CTA array will have the sensitivity or the observing time allocation to reach the dark-matter science goals described in *NWNH* and in the P5 recommendations. For NSF, the only available funding mechanisms to support CTA construction are the NSF/AST MSIP program and NSF/PHY Midscale Instrumentation Fund (NSF 13-118). These both support projects across their respective divisions and new projects must compete successfully against projects in all subfields.

#### **4.5.3 Summary Evaluation of Progress toward *NWNH* Goals**

The AAAC commends the NSF for moving LSST, the top ground-based priority in *NWNH*, into the construction phase, and for initiating the MSIP program. While NSF/AST is strongly supporting the MSIP program, the program budget is limited and is highly oversubscribed. *NWNH* recommendations were based on a projection of \$40M/yr funding for MSIP in contrast to the currently available \$14M/yr and the FY16 request of \$18.72M. Moreover, it is not possible to support even this reduced MSIP program as well as the GSMT and CTA recommendations at this time. The principal difficulty facing NSF in following through on the recommendations of *NWNH* comes from large budget obligations tied to support of existing facilities. To address this difficulty, NSF/AST initiated a portfolio review process to outline a plan for divestment from past projects to enable NSF to meet the scientific priorities of *NWNH* in the future. The status of the portfolio review is described section 4.6.

#### **4.5.4 Additional Priority Projects in coordination with P5**

**DES:** The Dark Energy Survey (DES) is an international project jointly funded by DOE, NSF, universities and international agencies to conduct a very large imaging survey to probe dark energy and the origin of cosmic acceleration. The DOE is responsible for the 3-square-degree, 570-megapixel CCD camera which is mounted on the Blanco 4-meter telescope at CTIO operated by NOAO (NSF). While optimized to probe dark energy, the survey data on 300 million galaxies, millions of stars, and tens of thousands of transients addresses a broad range of astrophysics and provides scientific guidance to strategic development issues for the larger LSST project. The second year of observing was completed in February 2015. Nearly the entire survey footprint has now been imaged more than one magnitude beyond the depth of the SDSS in all filters. The first major cosmological results and public data release will be based on the first two years of DES data.

**DESI:** The Dark Energy Spectroscopic Instrument (DESI) is a new massively parallel spectrograph to be installed in 2018 onto the Mayall 4-m telescope at Kitt Peak National Observatory, Arizona operated by NOAO. In 2014, P5 encouraged support for DESI as part of a broad-based dark energy program. DESI will provide a three-dimensional map of distant galaxies and quasars obtained through spectroscopy that is complementary to the LSST imaging survey. DESI is an international project jointly funded by DOE, NSF, universities, private foundations and international agencies. Since the congressional appropriations bill for FY15 included DESI as a line item for a Major Item of Equipment (MIE = DOE Office of Science budget item for large capital equipment projects), the project can start fabrication of long-lead components this year. DOE/OHEP and NSF/AST have previously signed a Statement of Principles (January 2013) for DESI, and are now planning a Letter of Agreement for use of the Mayall telescope.

**Direct Detection of Dark Matter:** *NWNH* identified understanding the nature of dark matter as a science frontier question; noting that clearly astronomical approaches (e.g. gravitational lensing, the distribution of gas, galaxy clustering, rotation curves, etc.) also require direct dark matter detection to disentangle the physics. This is more explicit in P5, which recommends moving ahead quickly with second-generation (G2) experiments and increasing investment so that planning for an international G3 experiment can proceed. In response, a suite of three G2 direct detection dark matter experiments was chosen in June 2014, supported by DOE Cosmic Frontier and NSF/PHY Particle Astrophysics. Two experiments, Super Cryogenic Dark Matter Search (SuperCDMS) and LUX-Zeplin (LZ) search for weakly interacting massive particles (WIMPs), and the Axion Dark Matter eXperiment (ADMX) is sensitive to axions. For DOE, the congressional appropriations bill for FY15 included LZ and SuperCDMS as line items for an MIE, allowing them to start fabrication of long-lead components this year. ADMX, as a smaller project, can move forward without this step. A lower budget scenario, as well as the decision to keep DESI on schedule for the Mayall telescope in 2016 (necessary if the NSF divestment process is to continue), has reduced the amount of money immediately available to direct dark matter experiments. The intent of both DOE and NSF/PHY is to locate money over the next several years to increase the investment in direct dark matter if resources permit.

**Cosmic Microwave Background:** Participation in CMB science through the development of a coherent ground-based Stage-IV CMB project in the next decade has been endorsed by DOE, but the schedule for this process is not fully defined. A rough budget was presented to P5 for their planning purposes. The P5 recommendations do not suggest a rigid timeline, acknowledging that the agencies need time to plan how to accommodate a new direction (for the DOE) and how to optimize collaboration among the DOE and NSF. The NSF, like NASA, has a long history and deep expertise in supporting CMB research in all phases, including expansion of observatory sites in appropriately high and dry regions and implementing millimeter and microwave telescope options. This infrastructure is complementary to the DOE's expertise with large-scale fabrication of science-grade detectors, with massive data sets, and with pulling together large but effective and productive collaborations of scientists. Since *NWNH* supported the development of CMB research, the mid-decadal review provides an excellent opportunity for community-based advice on future directions.

***FINDING: The highest priorities of NWNH: WFIRST and LSST, are moving forward.***

***FINDING:*** NSF/AST and DOE/HEP have done an excellent job in coordinating their efforts to make sure that LSST continues to make progress. Some delays in LSST and associated cost increases have resulted from the federal budget standoffs, but the agencies have provided good management to minimize the impact on the project.

***FINDING:*** NASA effort to reformulate the WFIRST-AFTA concept is well underway. The NASA plan offers the potential for realizing an even more powerful experiment for Dark Energy and Extrasolar planet science in a cost-neutral way.

***FINDING:*** The NSF MSIP program is funded at a level well below that envisioned in NWNH, but is becoming the only mechanism available for funding the high priority activities advocated in NWNH. By combining support for strategic objectives with an unsolicited open call for proposals, the program may become so oversubscribed that it can no longer effectively serve the community.

***FINDING:*** Despite budgetary constraints that did not allow progress on recommendations for a U.S. partnership in a large optical/infrared telescope (GSMT) and a major new X-ray telescope (IXO), the NSF is working on a U.S. Participation Plan for the TMT and NASA is anticipating future U.S. participation in the ESA ATHENA project providing future resources for the U.S. ground-based and X-ray communities.

***FINDING:*** NSF/AST and DOE/HEP continue to support a strong dark energy program with DES and a new MIE start for DESI in FY2014. Along with LSST and WFIRST/AFTA, this broad-based program across all three agencies is an excellent response to NWNH and P5 priorities in dark energy and cosmic acceleration.

***FINDING:*** DOE/HEP Cosmic Frontier and NSF/PHY Particle Astrophysics have selected three G2 direct detection dark matter detectors to move forward, however funding is not at the level recommended. Both agencies will continue to make the case for funding these at the level needed to carry them out successfully.

***FINDING:*** The international CTA consortium is moving forward to build the CTA observatory without U.S. financial participation. Despite positive recommendations in NWNH and the P5 report, DOE has declined to support participation of U.S. scientists in CTA. For NSF, the only available funding mechanisms to support CTA construction are the highly-competed NSF/AST MSIP program and NSF/PHY Midscale Instrumentation Fund.

***FINDING:*** Gravitational wave science remains one of the most exciting frontiers of physics and astrophysics, and its future development will benefit greatly from cooperation among the three agencies.

***FINDING:*** CMB science clearly crosses the boundaries of agencies. As recommended by P5, a larger role of DOE with NSF is important to realize the great scientific potential of this enterprise

***RECOMMENDATION:*** We encourage DOE and NSF to continue working toward a plan for the next generation (stage-IV) ground-based CMB observatory

***RECOMMENDATION:*** The agencies should continue to pursue international partnerships in order to further accomplish the goals of NWNH. The Principles for Access<sup>1</sup> should guide the process.

## **4.6 Status of the Portfolio Review**

The 2012 Portfolio Review Committee produced several recommendations toward accomplishing the goals of the NWNH Decadal Survey. These included divestment of several optical and radio facilities, as well as commitment to funding of individual guest investigator grants, REUs and Theory programs, and implementation of a Mid-Scale Innovations Program (MSIP).

During the past year, implementation progress has been made on several of these programs. The NSF has enlisted an engineering firm to study the current status and condition of telescopes and observatories as part of the assessment of future options. Many of these telescopes are still producing excellent science as outlined in the NWNH survey. In these cases, outside partnerships are being sought so that the U.S. community maintains at least some access to these facilities. The facilities recommended for divestment in the Portfolio Review include the

***KPNO 2.1m telescope:*** closed in August 2014, and for which NOAO has received proposals for partners to fund operations;

***WIYN telescope:*** part of the new NASA-NSF Exoplanet Observational Research (NN-EXPLORE) partnership;

***KPNO Mayall telescope:*** will host DESI, a survey funded by DOE;

***McMath-Pierce Solar telescope*** and ***Dunn Solar telescope:*** solar telescopes for which operating partners are being sought, and engineering studies are under way;

***Green Bank Telescope*** and ***VLBA:*** radio telescopes for which operating partners are being sought, and engineering studies are under way;

***University Radio Observatories:*** now fall into the MSIP category. No previously funded facilities have received funding under the new classification and they are seeking partners for continued operation.

Our committee notes that these divestments do not come without a considerable cost to the user community, especially those scientists working at institutions without their own telescope access. Many of these telescopes offer unique scientific capabilities. To mitigate these losses, NSF has actively explored international partnerships, interagency cooperation and private resources so that the U.S. community can maintain some access to these facilities. Of particular note, the recent NASA/APD and university partnership on the WIYN telescope have made it possible for NSF/AST to reduce its operating costs, and repurpose the instrument for support of NASA exoplanetary science. Partnership of NSF/AST and DOE/HEP CF on the DESI project will make it possible to repurpose this user-facility to serve as a dedicated spectroscopic survey instrument for dark energy science. Nonetheless, the 100% loss of the 2.1m and Mayall nights, and 40% of WIYN nights to open, varied science is not trivial. The open WIYN nights for exoplanet-related science means that community access to the instruments is necessarily reduced for those astronomers in fields other than those that will benefit from the new partnerships.



The potential loss of the VLBA and GBT will cripple the pursuit of two highly ranked scientific goals of NWNH, precision astrometry and nanohertz gravitational waves.

***FINDING: The NSF Division of Astronomical Sciences has done a commendable job of finding creative solutions to achieve the divestment recommended by the Portfolio Review without shutting down facilities. These actions serve to reduce their operating budgets and thus to enable key scientific priorities in NWNH.***

***FINDING: Divestments recommended by the Portfolio Review are proceeding, but at a slower pace due to complexities of the divestment process.***

***FINDING: The loss of open access facilities from the NSF portfolio does not come without a cost to the U.S. user communities, in terms of loss of open nights and access to a variety of instruments and science. This loss is especially critical for the researchers at institutions without their own telescope access or who use ground-based facilities that provide unique science capabilities.***

***RECOMMENDATION: Vigorous activities toward divestments recommended by the Portfolio Review should continue, along with agency efforts to explore partnerships, interagency cooperation and private resources to maintain some access to these facilities or their capabilities for the U.S. Divestments are necessary to increase the available funding for both strategic and unsolicited midscale and individual investigator programs.***

## **4.7 Preparation for Mid-Decadal Review**

In November 2014 the agencies formally requested a mid-decadal review. In addition to being a useful process for tracking and maintaining progress on the NWNH survey, it also satisfies the NASA Authorization Act of 2005, which requires an assessment of the Science Division's progress every 5 years. Together with the 10-yr Decadal surveys, the mid-decadal survey fulfills this legal requirement.

By incorporating the astronomy and astrophysics projects presided over by NSF and DOE, the mid-decadal survey is even more inclusive than legally required. The mid-decadal *draft* charge is as follows

*The National Research Council shall convene an ad hoc committee to review the responses of NASA's Astrophysics program, NSF's Astronomy program, and DOE's Cosmic Frontiers program (hereafter the Agencies' programs) to previous NRC advice, primarily the 2010 NRC decadal survey, "New Worlds, New Horizons in Astronomy and Astrophysics" (NWNH). In the context of funding circumstances that are substantially below those assumed in NWNH, the committee's review will include the following tasks:*

- 1. Describe the most significant scientific discoveries, technical advances, and relevant programmatic changes in astronomy and astrophysics over the years since the publication of the decadal survey;*
- 2. Assess how well the Agencies' programs address the strategies, goals, and priorities outlined in the 2010 decadal survey and other relevant NRC reports;*
- 3. Assess the progress toward realizing these strategies, goals, and priorities; and*

*4. In the context of strategic advice provided for the Agencies' programs by Federal Advisory Committees, and in the context of mid-decade contingencies described in the decadal survey, recommend any actions that could be taken to maximize the science return of the Agencies' programs.*

*The review should not revisit or alter the scientific priorities or mission recommendations provided in the decadal survey and related NRC reports but may provide guidance on implementation of the recommended science and activities portfolio and on other potential activities in preparation for the next decadal survey.*

In planning for the mid-decadal review, it will be important to understand differences among the three federal agencies involved. The degree to which each agency can use the mid-decadal as a stepping-stone to the next decadal survey is therefore also somewhat divergent.

*NWNH* contained a number of different scenarios depending on the budget realities. However, even the lowest-budget scenario was based on a more optimistic projection of the fiscal situation than has actually transpired. In addition, progress on WFIRST and other space-based projects has been affected by the fact that JWST has ended up costing more than was assumed at the time of the decadal survey. *NWNH* was the first decadal survey that included DOE; thus DOE is still trying to establish the ground rules by which it will participate in the mid-decadal review. DOE funding allocation is driven by the P5 process, rather than the astronomy and astrophysics decadal surveys. The agencies understand the need to collaborate to achieve the best use of resources for astrophysics and to keep interagency communication open. The AAAC is impressed by the close collaboration among all three agencies as they prepare a unified plan for the mid-decadal review.

The *NWNH* decadal survey report made recommendations regarding the tension between the operating costs for big facilities and small investigator grants. There was a specific recommendation to look at grants programs. There are differences in the NSF and NASA approach to grants; NASA has a formal community-driven process, whereas NSF responds to proposals from individual scientists. NASA is mission-driven whereas NSF takes guidance from the proposals themselves. Major facilities need longer-term plans, whereas small grants can be more responsive. Due to these fundamental differences, the approaches are not the same. Currently NASA is already considering options for their missions in the next decade as a means of preparing for the mid-decadal review, and looking ahead to the next decadal survey.

NSF prefers to keep their options open longer, since the next big facility would require a commitment of resources before there is knowledge of the operations funding wedge that is likely to be available ten years into the future. Compared to most other NSF divisions, the AST budget is dominated by big facilities. A successful divestment process, as recommended by the Portfolio Review, will begin to reduce the facility share in FY2016.

***FINDING: The agencies are commended for their collaboration in developing the mid-decadal survey process. This is the first mid-decadal review to include the NSF and DOE. They are successfully navigating the uniqueness of each agency, while maintaining a high level of coordination.***

## 5) Budget Summary and Impact

Recent economic challenges have severely constrained federal spending on many programs of importance to the nation. In this decade, enacted budgets for astronomy and astrophysics are below the most pessimistic projections of the recent long-term strategic planning exercises, such as the two most recent Decadal Surveys, *NWNH* and *AANM (Astronomy and Astrophysics for the New Millennium)*. This has limited the ability of funding agencies to implement the priorities of the long-term strategic plans, delaying scientific discoveries and forcing divestments of facilities. Top priorities of the decadal survey will not be built or will be delayed into the next decade and most individual investigator grants and midscale programs have seen falling success rates (discussed in the next section).

The easing of our nation's economic challenges offers an opportunity to restore the decadal priorities and the nation's scientific leadership in astronomy and astrophysics. While the recently released President's Budget for 2016 proposes an overall increase of 6% in federal investment in research & development (R&D)<sup>8</sup>, enacting this increase would require changes to the Budget Control Act. Even within that optimistic scenario, the proposed budget for astronomy and astrophysics is flat.

Including JWST, the NASA Astrophysics budget decreases from \$1372 million in FY 15 (appropriated) to \$1330 million in FY16 (requested). The Science Mission Directorate's STEM education and public outreach allocation is not included in these budget numbers. The FY16 request includes SOFIA operations in full. For the top NWNH priority in space, WFIRST the request has \$36 million less than last year's appropriation, however the expectation is that WFIRST will ramp up in the budget's notional out-years as JWST ramps down.<sup>9</sup> On the positive side, NASA's astrophysics Research and Analysis program has a 10% increase in the 2016 request and JWST remains on its cost baseline.

For NSF, the request includes a 5.2% increase over FY 2015 enacted, however the Mathematical and Physical Sciences (MPS) directorate received only a 2.2% increase in the request over FY 2015, and the AST division received a 1% increase (\$2.4 million) over FY 2015, with a welcomed growth in the Mid-Scale Innovations Program (MSIP). The NSF Major Research Equipment and Facilities Construction (MREFC) budget supports the construction of LSST and DKIST at \$120 million (of the total \$200 million). However, the individual investigator grants (AAG) program lost \$2.7 million (-6.6%) relative to FY 2015 in this request.

The DOE Office of Science received a 5.4% increase compared to FY 2015 enacted, with High Energy Physics (HEP) rising 2.9% compared to FY 2015 in the request (\$22 million). The Cosmic Frontier Program request provides an additional \$12 million compared to FY 2015 enacted. Most of the increase is for the LSST Camera construction, and to begin new projects in dark matter and dark energy, including the Dark Energy Spectroscopic Instrument (DESI) that began working towards installment on the Mayall 4-m telescope at Kitt Peak helping NSF to at least partially divest the Mayall. The FY16 President's request for DOE HEP as a whole is above Scenario B of P5. The fraction of that assigned to DOE/CF was determined

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<sup>8</sup> <http://www.aas.org/news/white-house-proposes-146-billion-federal-rd-support-fy-2016>

<sup>9</sup> <https://aas.org/posts/blog/2015/02/presidents-fy-2016-budget-just-dropped>

before P5 and may be adjusted. In addition, there is flexibility within DOE/CF to move some of the G1 dark matter operations money to make a G2 wedge as projects move forward.

Budget in \$M	FY 2014	FY 2015	FY 2016 Req.	change 16-15	change 16-14
NASA Astrophysics (NASA/APD)	\$678.3	\$726.8	\$709.1	-2.4%	4.5%
NSF Astronomical Sciences (NSF/AST)	\$238.4	\$244.2	\$246.6	1.0%	3.4%
DOE HEP Cosmic Frontier (DOE/HEP CF)	\$96.9	\$105.5	\$119.3	13.1%	23.1%
Totals	\$1,013.6	\$1,076.5	\$1,075.0	-0.1%	6.1%
James Webb Space Telescope (JWST)	\$658.2	\$645.4	\$620.0	-3.9%	-5.8%
DOE Large Synoptic Survey Telescope (LSST)	\$22.0	\$35.0	\$40.8	16.6%	85.5%
NSF Large Synoptic Survey Telescope (LSST)	\$27.5	\$79.6	\$99.7	25.3%	262.5%
Daniel K. Inouye Solar Telescope (DKIST)	\$36.9	\$25.1	\$20.0	-20.3%	-45.8%

***FINDING: The 2016 President's Budget request proposes an overall 6% increase in R&D investment, while astronomy and astrophysics (NSF/AST, NASA/APD, DOE/HEP CF) would be flat (-0.1%) in nominal dollars before inflation, when large facility/mission construction is not included.***

***RECOMENDATION: We urge the agencies and Congress to recognize the important role of basic research to the future of our country, including the special contributions that astronomy and astrophysics can offer. Additional investments will lead to great advances and breakthroughs and the bold vision for U.S. astronomy and astrophysics endorsed in the NWNH report.***

## 6) Proposal pressures and falling success rates

### 6.1 Overview

Over the last decade, there has been a steep rise in the number of proposals for individual investigator grants and mid-scale programs. The 2014 AAAC report noted this in their findings and recommended that the AAAC and the agencies should work together to clarify and quantify the impact of this situation. In response to this recommendation, a Proposal Pressures Study Group has been formed under the auspices of AAAC, including representatives from CAA, AAS, and NAC in consultation with representatives from the relevant divisions of NSF, DOE and NASA. Its purpose is to evaluate the effect of this changing environment on the health of the field, specifically addressing whether this will result in unacceptable restrictions in the range of new scientific initiatives and negatively impact career choices of the most promising researchers. This situation is creating an unsustainable load on reviewers and on the agencies in cost and manpower.

As an example, the number of proposals submitted to the NSF/AST Astronomy and Astrophysics Grant (AAG) program from FY05 to FY15 has increased by 84%, but available funding has not risen commensurately. Success rates have plunged to 15% from roughly 30% in 2005. A timely and successful divestment process can keep acceptance rates at ~15%. In the absence of facility divestments by NSF/AST over the coming years, the proposal success rate is projected to decline to an extremely low level of ~10% in FY19, as shown in Figure 1.

This study group will gather relevant proposal and demographic data from both the agencies and the community in order to understand how the funding environment over the last 10 years has affected researchers and projects. A short progress report is presented here with a final report later in the year.

## AAG % Future Success Rates in the Absence of Facility Divestment

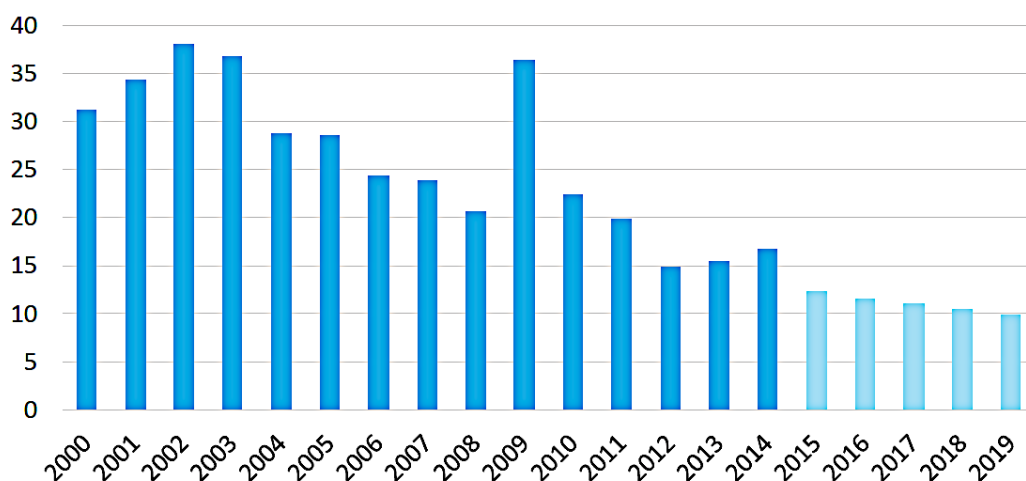


Figure 1. Projected NSF/AST (AAG) proposal success rate<sup>10</sup> in the absence of facility divestment. If divestment continues on schedule, the budget continues flat, and the number of proposal submissions does not increase substantially, the success rates will remain at roughly 15%. (Data from NSF/AST.)

## 6.2 Summary of Preliminary Findings and Recommendations

In examining the publicly available data, several important questions have already been answered. NSF/AST data show that the rise in proposals is driven largely by an increase in the number of investigators, each submitting a single proposal. The proportion of individuals submitting two or more proposals has only experienced a modest rise from 16% to 21%. Data from NASA do not have as straightforward a breakdown, but the same story emerges. For example, in 2014 NASA Astrophysics Research Opportunities in Space and Earth Sciences (ROSES) programs (specifically ADAP, ATP, WPS and XRP) received 573 proposals from 476 PIs<sup>11</sup>. In 2008 (2009) the number of proposals was only 290 (393). Thus we know that there were no more than 290 (393) unique PIs in 2008 (2009), compared to 476 in 2014. Note that this does not address whether individuals are submitting a larger number of similar proposals to multiple agencies.

The possibility that funding opportunities and fellowships targeting postdocs have generated additional proposals from new PIs, is also not borne out by the statistics. Indeed, the proportion of submitting PIs who are less than 15 years since PhD has declined somewhat in NSF Astronomy, from ~50% in FY06 to

<sup>10</sup> [http://www.nsf.gov/attachments/131083/public/Dan-Evans\\_AST\\_Individual\\_Investigator\\_Programs-AAAC\\_Meeting.pdf](http://www.nsf.gov/attachments/131083/public/Dan-Evans_AST_Individual_Investigator_Programs-AAAC_Meeting.pdf)

<sup>11</sup> [http://science.nasa.gov/media/medialibrary/2014/04/09/2014.03.27\\_ApS\\_RA\\_final-2.pdf](http://science.nasa.gov/media/medialibrary/2014/04/09/2014.03.27_ApS_RA_final-2.pdf)

~45% in FY15. In NSF/PHY Particle Astrophysics, the fraction of younger PIs was small<sup>12</sup>, when the division was created in FY2000, so the uptick in younger researchers since then has simply brought it into the same balance observed by NSF/AST over the last decade.

There is also no significant change in the proportion of institution types submitting proposals, and overall there continues to be an appropriate balance in award rates according to gender and minority status.

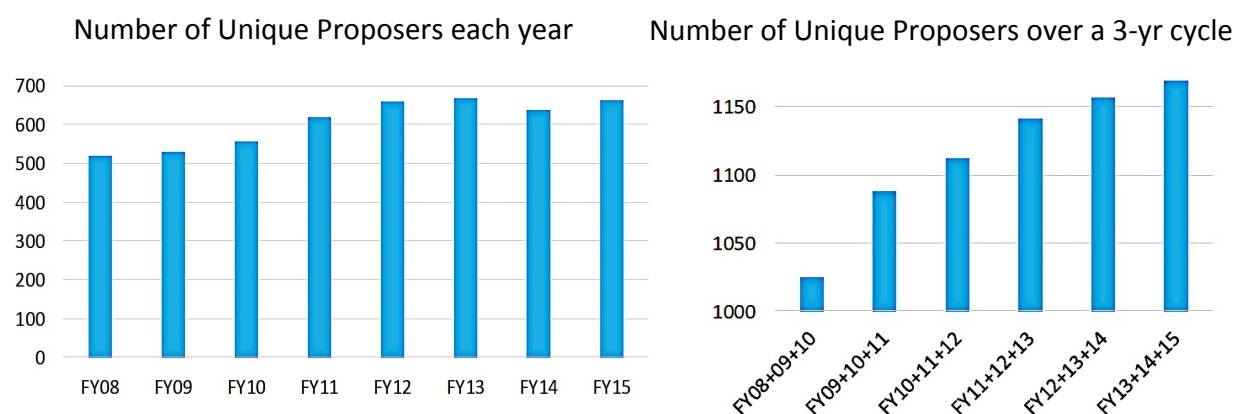


Figure 2. Trending plots showing the number of unique individuals submitting to NSF/AST AAG program as PI each year, as well as the sum over 3 years corresponding to a typical grant cycle. Declined proposals can be re-submitted the next year, but PIs with accepted proposals will not resubmit for the same project until after 3 years. (Data from NSF/AST.)

Figure 2 shows that the average number of unique proposers per year over a typical 3-year grant cycle (the number in the right panel divided by three) is less than the actual number proposing each year (left panel), indicating that unsuccessful proposals are resubmitted the following year. We do not have direct information on how many of the proposals are new and how many are repeats, but these data imply that the fraction of repeat proposals to new proposals is rising. Thus, the decline in proposal selection rates are causing more senior investigators to reapply in consecutive years, driving up the number of proposals and driving down the success rates even further.

It is worth mentioning that the DOE/HEP funding model is very different. Many DOE grants are block grants in which multiple faculty members are funded. Often these grants cover multiple frontiers. This allows them to share resources and get better overhead rates. Since DOE is mission-driven, proposals are judged on their relevance to the DOE/HEP CF priorities, which are well-known to the proposers. Thus, their acceptance rates are much higher to begin with and DOE/HEP CF has not experienced a large rise in the number of submitted proposals. There has not been much change in the type of University group submitting grants. DOE/HEP does not typically collect demographic data, so conclusions based on gender, minority status or years since PhD cannot be drawn.

<sup>12</sup> NSF/PHY Program in Particle Astrophysics data. Provided by J. Whitmore.

For NASA/APD and NSF/AST, the bottom line is not whether fewer proposals overall are being funded, but whether a smaller fraction of excellent proposals are being funded. A larger proportion of poor proposals will primarily impact agency workload rather than science reach and topic diversity. Anecdotally, program officers note that, in their judgment, the number of truly outstanding proposals that go unfunded is definitively on the rise. Unfortunately, it is difficult to find a quantitative measure of this by simply comparing scores because reviewer perceptions of what constitutes an excellent proposal vary from panel to panel. The DOE review process allows reviewers to change their scores, in which case they represent a consensus ordering of proposals, the order of which also depends on programmatic advice.

NASA/APD has tracked scores for many years and has some confidence in the stability of the scale. Since they (like NSF/AST) conduct confidential reviews where the scores cannot be adjusted, NASA data<sup>10</sup> provide some indication of the trends. Figure 3 compares the distribution of R&A proposal grades in FY12 and FY13. The number of strong proposals with grades of VG (Very Good) or E (Excellent) fell by 10%, from 46.7% to 41.9%. However, the decrease in funding rate among these strong proposals dropped by 24%. Putting this together with 2007-2008 selection data from all Science Mission Directorate ROSES programs<sup>13</sup> (not just Astrophysics, as shown in Figure 3), a pattern emerges. While the success rate for VG/E and E remain stable at >75% and >90% respectively over all programs, the number of funded proposals in the VG category is rapidly falling from 45% in 2007-2008 to 25% in 2012 and only 7% in 2013.

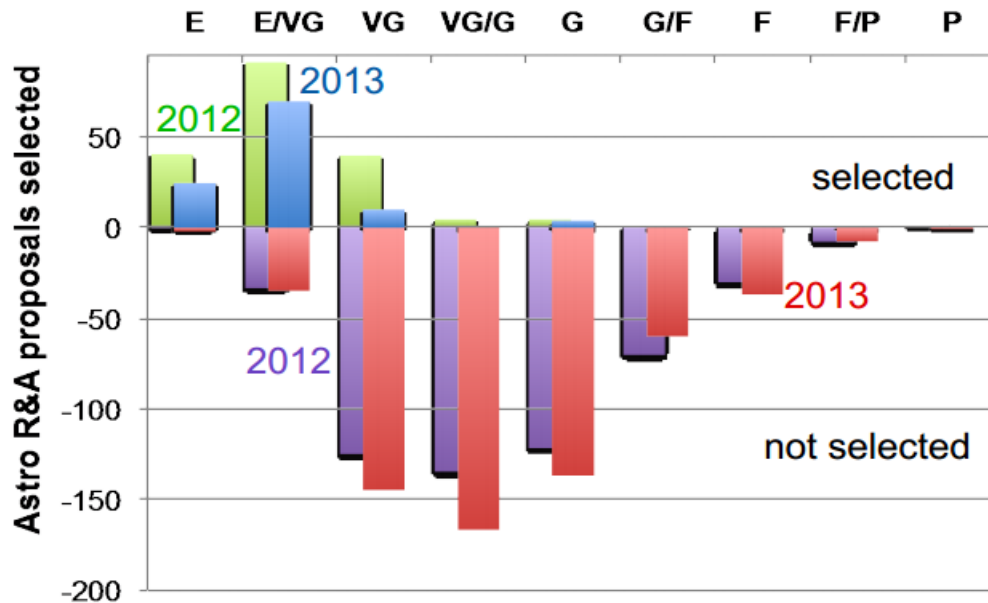


Figure 3: Number of NASA Astrophysics R&A proposals selected (above zero on vertical axis) or declined (below zero) in FY12 and FY13.

<sup>13</sup> <http://science.nasa.gov/researchers/sara/grant-stats/a-plot-of-grades-vs-who-gets-selected/>

### 6.3 Impact on Agencies

A challenge posed by the increased proposal load is how to manage proposal reviews. Although staffing has remained relatively flat in recent years, there have been more panels, each with a higher number of proposals. The organization and execution of just one panel takes 130+ hours of each NSF Program Officer's time. NSF has developed a number of tools to optimize the internal review processes, but another 30% increase in proposal volume over the next five years would not be sustainable. In 2014, NASA/APD handled 832 proposals in its core R&A programs. The estimated cost of this in NASA staff time and direct expenses for reviewer travel, meeting space, etc. to plan, execute, and document the evaluation and selection process is ~\$3M.<sup>14</sup>

Another issue is recruitment of reviewers. This is a problem for NSF/AST who do not allow an individual listed as PI or co-PI on an NSF/AST AAG proposal to serve as a reviewer. The result is that over 1,100 qualified individuals are prohibited from joining a panel. It is thus more difficult to recruit un-conflicted senior members of the community to join the panels. Reviewer acceptance rates have been falling; currently only 20-25% of reviewers agree to serve when asked. For NASA, conflict of interest issues can often be mitigated by putting the reviewer on a different panel from the problematic proposal. The growing number of proposals has not yet caused an increase in COI issues for NASA.

### 6.4 Impact on Researchers

The impact of low success rates on researchers is harder to quantify. The Proposal Pressures Study Group has therefore begun to draft a set of survey questions that address issues that cannot be extracted from the statistics collected by the agencies. We are especially interested in how proposal pressures are affecting career choices and productivity. For example, is the reaction to this stress a function of research sub-field, positions held, or years since PhD? Demographic information will be requested including employment status and type of institution. Questions will probe number of proposals submitted, agency applied to, and service on review panels. The questionnaire will end with a set of statements evaluating the effect of grant proposal success rate on careers with multiple choice responses from strongly agree to strongly disagree. Written comments will also be encouraged. The draft questions will be incorporated in a proposal to the AAS for funding such a survey. Upon successful review, the survey will then be professionally administered and analyzed by AIP.

***FINDING. Over the last decade, the number of individuals submitting proposals to NSF and NASA in the fields of astronomy and astrophysics is increasing faster than the funding profile, causing a corresponding drop in selection rate. A larger fraction of very good to excellent proposals are unsuccessful now than in the past. Such a low selection rate for very good proposals is incompatible with the healthy individual investigator programs recommended by NWNH, and may represent a significant loss of science.***

***FINDING. After accounting for changes in agency opportunities, NSF and NASA data show that the PIs submitting these proposals have remained a relatively stable demographic entity in terms of race, gender, number of years since PhD, and type of Institution.***

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<sup>14</sup> NASA/APD Data. Provided by Hashima Hasan



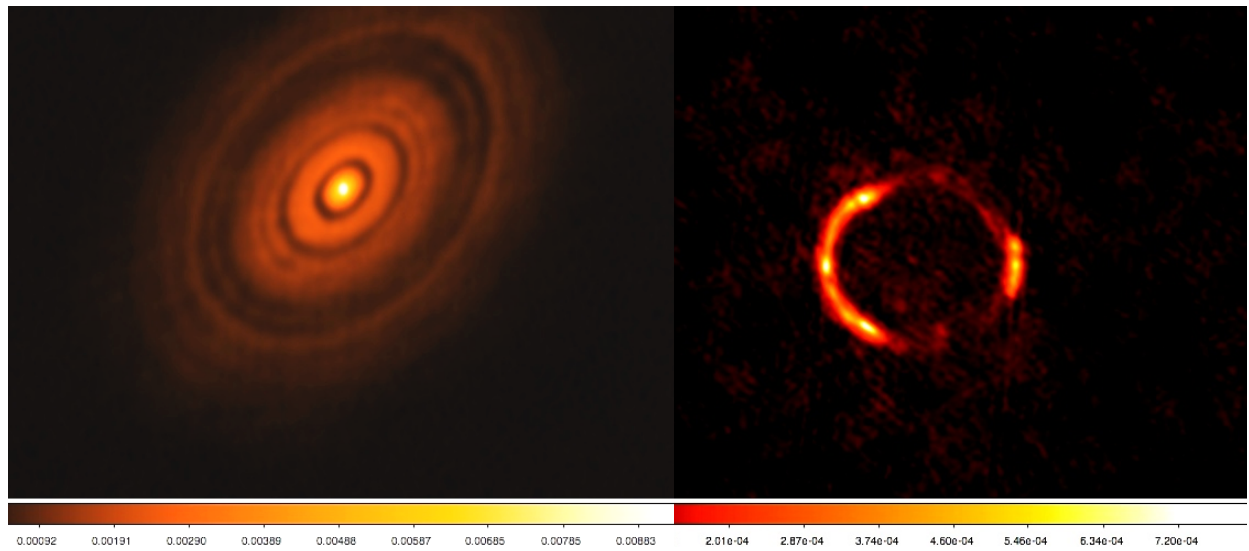
***FINDING. A falling success rate impacts both researchers and agencies. Researchers spend a larger fraction of time re-submitting proposals and serving on multiple review panels. Agencies must deal with an increased workload, staffing problems, and ensuring fair review panels with sufficient reviewers.***

***RECOMMENDATION: The agencies should continue to work with the astronomy and astrophysics community to clarify and quantify the underlying factors contributing to the declining success rate seen at NASA and NSF, and develop data-driven ideas for managing the problem.***

## Appendix A: Advances in science and development of new projects

**A1.** The Atacama Large Millimeter/submillimeter Array (ALMA) commissioned its long baselines with science verification projects. Two striking examples of the type of data accessible by the new telescope array are shown in Figure A1: the protoplanetary disk of the star HL Tau and the distant lensed galaxy SDP.81. Both images had spatial resolutions of 30 milli-arcseconds, ten times better than ground-based arrays and more than 200 times better than can be achieved by single dish submillimeter telescopes.

HL Tau is a sun-like star that is very young, less than a million years old. It is hidden from view in visible light, but the submillimeter waves that ALMA detects can penetrate through the gas and dust to the star and its young planetary system, which is revealed by emission from dust within the disk. The gaps in the protoplanetary disk that are clearly revealed are caused by the gravitational clearing of paths by forming planets. This is a surprising and unexpected result, since planetary systems this young are not expected to have yet formed planets large enough to clear the observed gaps.

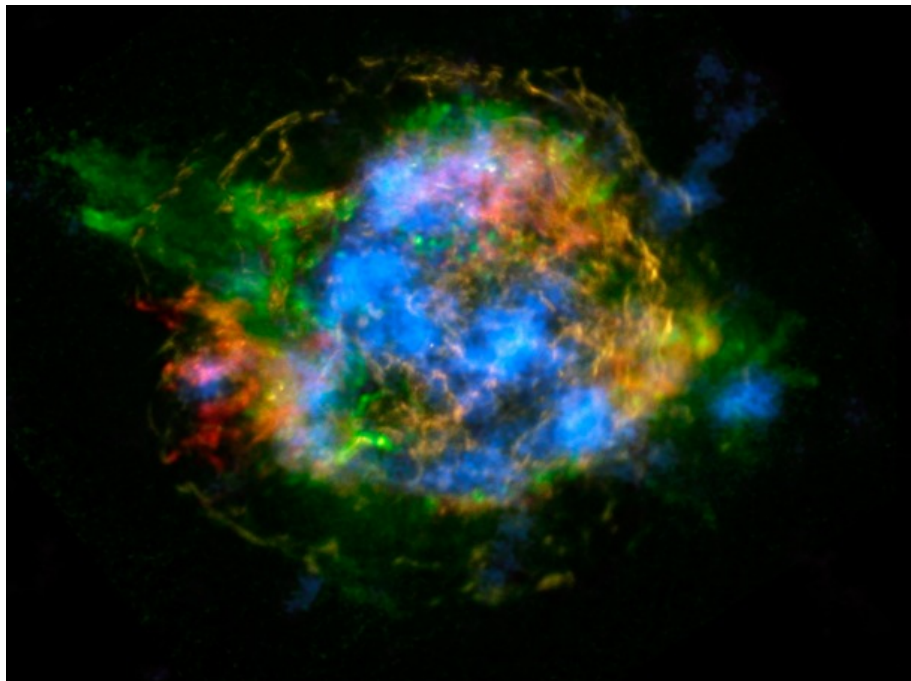


*Figure A1. Pictures from the ALMA science verification data. Left: A planetary system in formation around the young sun-like star HL Tau. Right: An ultra-luminous distant galaxy (SDP.81) magnified and distorted into an Einstein Ring by the lensing effect of a cluster of galaxies along its line of sight.*

If it were not for the gravitational lensing (by an intervening galaxy cluster), galaxy SDP.81 would have been too faint to detect by ALMA. This unique observation provides a view of an ultra-luminous galaxy at  $z=3$ , when the Universe was only 15% of its current age, and demonstrates how the magnification enhancement of gravitational lensing allows us to detect galaxies at much greater distances. Improvements in spatial resolution allows ALMA to resolve a nearly perfect Einstein ring, only seen when an imaged system is positioned directly behind the lensing foreground mass. Analysis of the ALMA image allows one to study the structural properties of the lensing dark-matter mass distribution of the

foreground galaxy cluster, as well as to make new measurements of the stellar population in this very distant galaxy created in the early Universe.

**A2.** The Nuclear Spectroscopic Telescope Array (*NuSTAR*) mission is the first imaging high-energy X-ray telescope to operate in the band from 3 to 79 keV. Unlike previous high-energy X-ray missions that used non-imaging optics, NuStar makes use of focusing X-ray optics. NuStar's camera is also unique; unlike traditional electronic cameras (e.g. CCDs), the camera is based on CZT semiconductor elements that simultaneously provide imaging, spectroscopy and timing. Rather than integrating signals in discrete color bands, this instrument determines the energy and arrival time of each detected photon. The novel optical design makes use of state-of-the-art grazing-incidence X-ray mirrors (capable of reflecting even very high energy X-rays) and a very large focal length achieved by deploying a 10m long boom between the camera and optics after launch. Combining these unique design features allows *NuSTAR* to probe the hard X-ray sky with a more than 100-fold improvement in sensitivity, providing a new window on the high-energy Universe. In the few years since its launch, NuSTAR has made numerous discoveries about exploding stars, black holes, pulsars, active galaxies and even our own sun.



*Figure A2. An X-ray image of the Cassiopeia A supernova remnant made with NASA's Nuclear Spectroscopic Telescope Array, or NuSTAR. In this image, NuSTAR data, which show high-energy X-rays from radioactive material (titanium-44) are colored blue. Lower-energy X-rays from non-radioactive material, imaged previously with NASA's Chandra X-ray Observatory, are shown in red, yellow and green.*

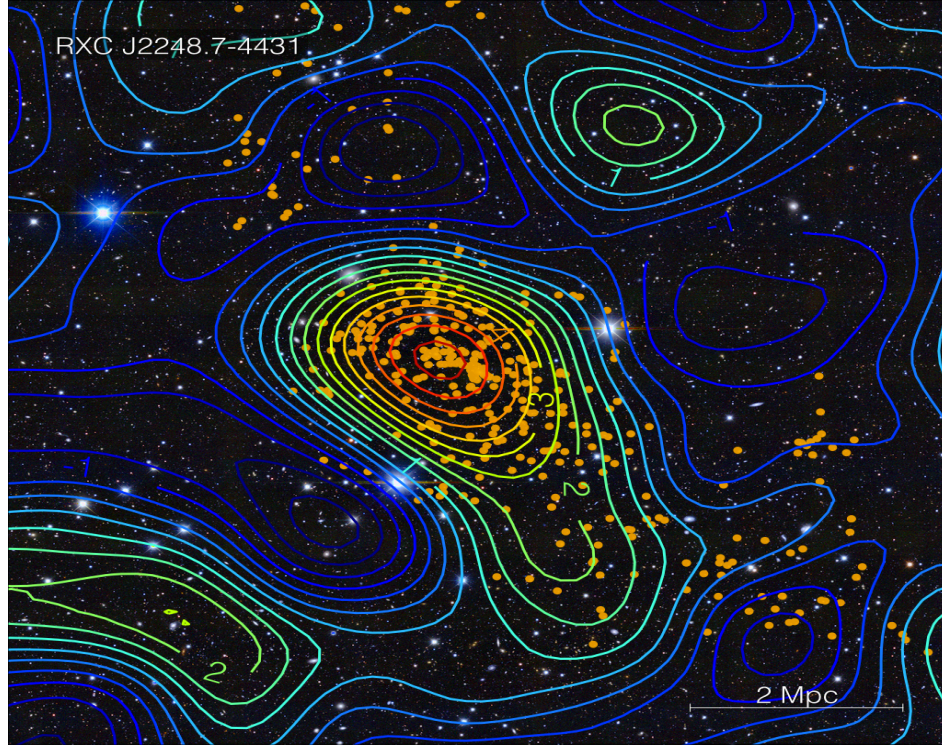
One recent highlight from NuSTAR, published in *Nature*<sup>15</sup> last year, is observation of the distribution of radioactive nuclei in the supernova remnant, Cassiopeia A (Cas-A). Since light from Cas-A first reached the Earth only a few hundred years ago, these observations provide an image of a relatively young supernova remnant not long after the explosion of a massive star. Scientists have long known that many of the extended nebulae in the galaxy are actually the remnants of exploding stars. Understanding the evolution of stars, and their eventual deaths as supernovae, is key to understanding the chemical history of the Universe. Our own solar system is formed of chemical elements synthesized in previous generations of stars and supernovae explosions. Supernovae produce many of the heavy elements in the Universe, from the gold in jewelry to the calcium in bones and the iron in blood. NuSTAR is the first instrument capable of producing maps of radioactive material in supernova remnants. Figure A2 shows a map of clumps of the radioactive nucleus titanium-44. The appearance of clumps of titanium concentrated in the center of the remnant points to a possible solution to a long-standing mystery of how stars like the progenitor of Cas-A meet their demise. Computer modeling of supernova blasts has often failed to reproduce the observed explosion; as the simulated massive star dies and collapses, the main shock wave often stalls out and no supernova explosion results. The NuSTAR findings strongly suggest the exploding star resulted in violent instabilities and mixing of material, re-energizing the stalled shock wave and allowing the star to blast off its outer layers.

**A3.** During the first two observing seasons of the Dark Energy Survey (DES), more than 36,000 on-sky exposures were taken to image most of the 5000 deg<sup>2</sup> survey area 4 times in each of 5 filter bands. This data sample now encompasses the largest volume of the Universe observed by an optical, near-infrared galaxy survey and is expected to form the basis for the first major cosmological results from DES and an initial public data release. While data from the first two seasons were being taken, the DES collaboration analyzed images from the science verification period that preceded the start of the survey in 2013. Discoveries from early analyses of these data include:

- A tidal disruption event at  $z=0.16$
- High redshift QSOs at  $z>6$
- Over 1000 supernovae to redshift  $z=0.9$  and beyond.
- Superluminous supernovae, including one at redshift  $z=1.3$
- ~20 trans-Neptunian minor planets in the time-domain survey alone
- Strongly lensed galaxies
- Detection of lensing of the cosmic microwave background by DES galaxies
- Detection of weak gravitational lensing of DES galaxies by large-scale structure. See Figure A3 from a recently published DES analysis (arXiv:1405.4285)
- Detection of 8 ultra-faint Milky Way Companions (arXiv:1503.02584).

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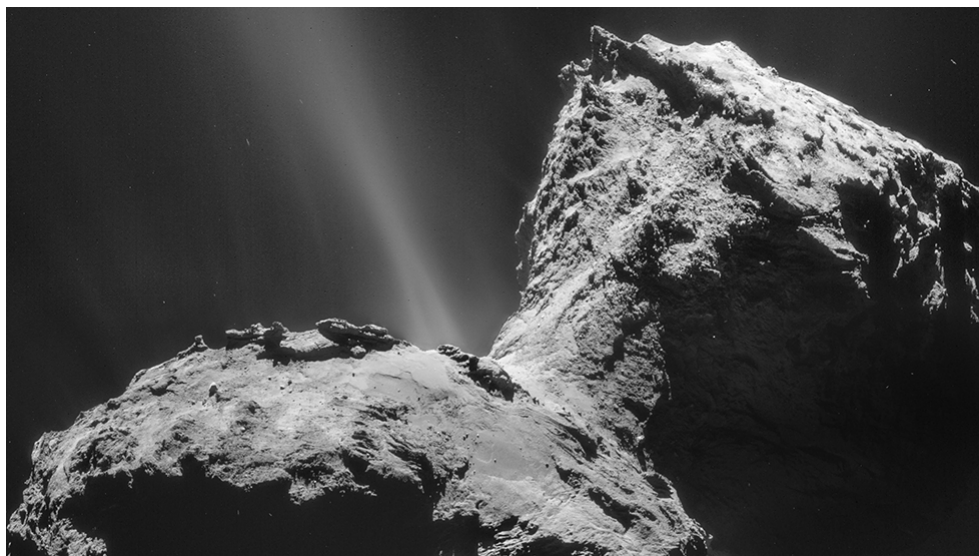
<sup>15</sup> B.W. Grefenstette, F.A. Harrison, S.E. Boggs, et al., “Asymmetries in Core-Collapse Supernovae from Maps of Radioactive 44-Ti in Cassiopeia A”, *Nature*, **506**, 339 (2014)



*Figure A3. Image of a galaxy cluster made with DES, together with contours showing the distribution of dark matter by weak lensing. The  $0.25 \text{ deg}^2$  image – about the size of the full moon – shows the galaxy cluster RXC J2248.7-4431 at redshift of 0.35 with a mass of  $17.5 \times 10^{14} M_{\odot}$ . A cluster finder algorithm was used to detect cluster member galaxies (orange dots) and a weak lensing analysis revealed the mass distribution surrounding this cluster which is dominated by dark matter (contours).*

**A4.** NASA often collaborates with the space agencies of other countries in order to maximize scientific return and avoid duplication of efforts in achieving important scientific goals in space exploration. The European Space Agency’s flagship *Rosetta* mission carries three scientific instruments supplied by NASA. The *Rosetta* spacecraft was launched in March 2004, and finally caught up with Comet 67P/Churyumov–Gerasimenko and began flying in formation with the comet in August 2014. November 12, 2014, *Rosetta* deployed the *Philae* landing probe to achieve the first soft landing on a comet. The harpoons that were to hold the *Philae* lander on the surface malfunctioned, and *Philae* bounced twice before settling onto the comet surface. The *Philae* instruments returned a significant amount of new data before *Philae* went into hibernation until its solar panels are able to recharge its batteries when they receive more sunlight.

One of the goals of *Rosetta* is to measure the ratio of “heavy hydrogen” (deuterium) to normal hydrogen in the water ice of the comet, and to compare that value to the ratio found on Earth. This will tell us whether Earth received most of the water in our oceans from comet impacts early in its history. The value measured by *Rosetta*<sup>16</sup> for comet 67P/Churyumov–Gerasimenko shows that comets such as this one probably did not supply the Earth with the bulk of its water, but it does not rule out other types of comets.



*Figure A4. Rosetta NavCam images of comet 67P/Churyumov–Gerasimenko taken on 31 January 2015. This four-image mosaic comprises images taken from a distance of 28.0 km from the center of the comet. The scene provides a stunning view of both the comet’s larger lobe (bottom) and smaller lobe (top right). A prominent jet and other outflows are also portrayed in the image. The overall activity of 67P/C-G is evident in the way that the silhouette of the nucleus stands out against the faint glow of the comet’s coma, especially in the darkest regions (bottom left and far right).*

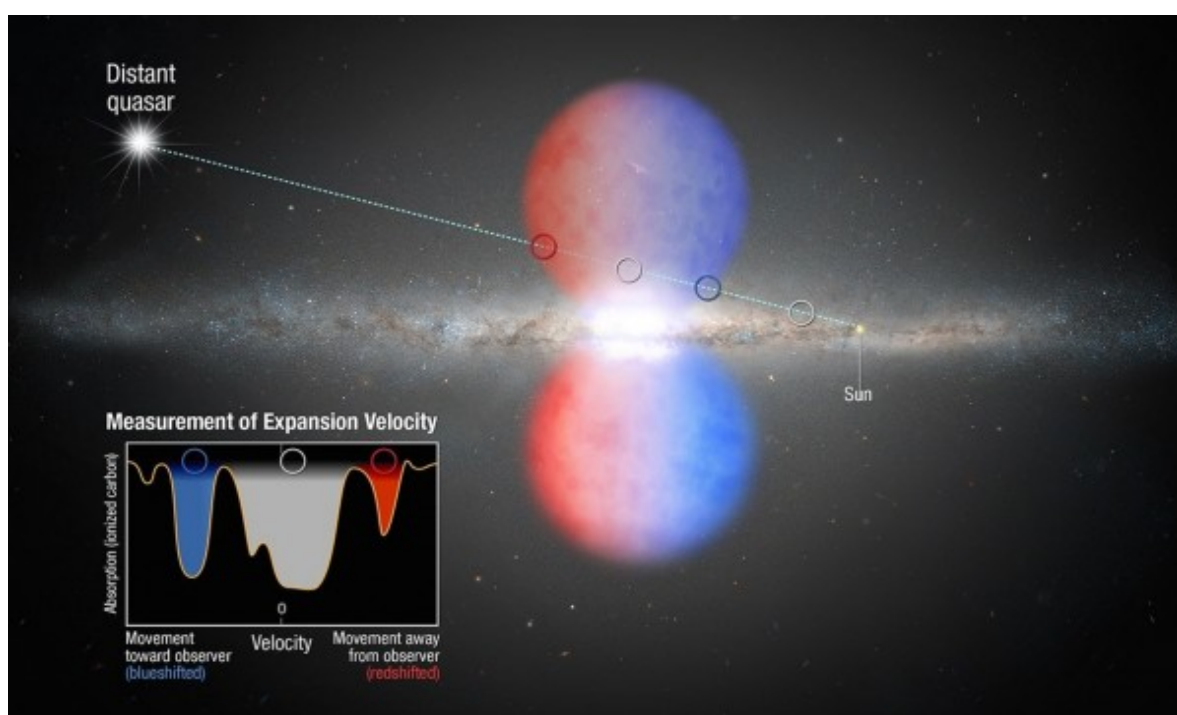
**A5.** Thorne-Zytkow objects, (TZOs) containing a neutron star imbedded inside a red supergiant, were predicted in 1975. However, it is only in the last year that a viable candidate has been observed to actually exist. The object was found in the SMC using high resolution Echelle Spectra from the 3.5m telescope at APO and the 6.5m Magellan telescope that revealed unusually strong Li and heavy element lines (Rb, Ni, Mo) in the spectrum. This detection<sup>17</sup> gives the first direct evidence for a different model for the resulting interiors of massive binary systems (where the unusual neutron star core provides the energy source for the red supergiant rather than nuclear fusion). If these objects are as common as the discovery suggests, then it implies a new channel for the production of these elements in the Universe.

<sup>16</sup> Altwegg et al., *Science* **347**, 1261952-1 (2015)

<sup>17</sup> Levesque, E., Massey, P., Zytlow, A., Morrell, N. 2014, *MNRAS*, 443, 94L



**A6.** The Fermi Bubbles are giant plasma lobes discovered 5 years ago that extend tens of thousands of light years above and below the Galactic Center. They emit in gamma, X-ray and microwaves, but are invisible in optical light. Using a sight line through the northern lobe structure, high velocity metal absorption lines were recently observed<sup>18</sup> with the Cosmic Origins Spectrograph on Hubble Space Telescope that match the X-ray structure of the Fermi Bubbles. These data reveal that the gas is enriched in heavy elements resulting from the remnants of star formation, and it is driving the bubbles out from the galaxy core at more than 2 million miles/hour. This provides a new means to probe activity at the Galactic center. Figure A5 illustrates how light from a distant quasar is absorbed by the plasma, creating absorption lines seen by the Hubble Telescope. The red-shifted lines (far side of lobe) and the blue-shifted lines (near side) provide a measure of the plasma expansion velocity.



*Figure A5. Giant plasma lobes streaming outward from the galactic center. Their huge velocity (color-coded) was determined from newly discovered heavy-element spectral lines detected by the Cosmic Origins Spectrograph on Hubble Space Telescope.*

<sup>18</sup> A. Fox, et al., ApJ Letters **799**, 7 (2015)

## Appendix B: Explanation of Acronyms

AAAC	Astronomy and Astrophysics Advisory Committee
AAG	Astronomy and Astrophysics Grant
AANM	The 2000 NRC report “Astronomy and Astrophysics for the New Millennium”
AAS	American Astronomical Society
ACTA (or CTA)	Atmospheric Čerenkov Telescope Array
ADAP	Astrophysical Data Analysis Program
AFTA	Astrophysics Focused Telescope Assets
ALMA	Atacama Large Millimeter/ <b>submillimeter</b> Array
APRA	Astrophysics Research and Analysis
ATHENA	Advanced Telescope for High Energy Astrophysics
ATP	Astrophysics Theory Program
ATST	Advanced Technology Solar Telescope
CAA	The National Research Council’s Committee on Astronomy and Astrophysics
CAPP	AAS Committee on Astronomy and Public Policy
CARMA	Combined Array for Research in Millimeter-wave Astronomy
CD	Critical Design review
CF	Cosmic Frontier
CMB	Cosmic Microwave Background Radiation
CTA (or ACTA)	Atmospheric Čerenkov Telescope Array
DES	Dark Energy Survey
DESI	Dark Energy Spectroscopic Instrument
DKIST	Daniel K. Inouye Solar Telescope
DOE	Department of Energy
DOE/HEP CF	Department of Energy High Energy Physics at the Cosmic Frontier



DPF	Division of Particles and Fields (of the American Physical Society)
ESA	European Space Agency
FACA	Federal Advisory Committee Act
FDR	Final Design Review
FOC	Full Operational Capability
FGST	Fermi Gamma-ray Space Telescope
FY	Fiscal Year
GSMT	Giant Segmented Mirror Telescope
HEP	High Energy Physics
HEPAP	High Energy Physics Advisory Panel
ISIM	Integrated Science Instrument Module
ISS-CREAM	International Space Station Cosmic Ray Energetics and Mass
IXO	International X-ray Observatory
JAXA	Japan Aerospace Exploration Agency
JWST	James Webb Space Telescope
LSB	Long Duration Balloon
LISA	Laser Interferometer Space Antenna
LSST	Large Synoptic Survey Telescope
MIE	Major Item of Equipment
MPS	Mathematical & Physical Sciences (NSF Directorate for ...)
MREFC	Major Research Equipment and Facilities
MSIP	Mid-Scale Innovation Program
NAC	NASA Advisory Council
NASA	National Aeronautics and Space Administration
NASA/APD	National Aeronautics and Space Administration Astrophysics Division

NSB	National Science Board
NRC	National Research Council
NSF	National Science Foundation
NSF/AST	National Science Foundation Division of Astronomical Sciences
NSF/PHY	National Science Foundation Physics Division
NWNH	The 2010 NRC decadal survey report “New Worlds, New Horizons in Astronomy and Astrophysics”
OHEP	Office of High Energy Physics, DOE
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
P5	Particle Physics Project Prioritization Panel
PASAG	Particle Astrophysics Scientific Assessment Group
PRC	National Science Foundation Portfolio Review Committee
R&D	Research and Development
SDSS	Sloan Digital Sky Survey
SOFIA	Stratospheric Observatory for Infrared Astronomy
SPT	South Pole Telescope
SXS	Soft X-ray Spectrometer
VERITAS	Very Energetic Radiation Imaging Telescope Array System
WFIRST	Wide-Field Infrared Survey Telescope
WPS	WFIRST Preparatory Science
XRP	Exoplanet Research Program